This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

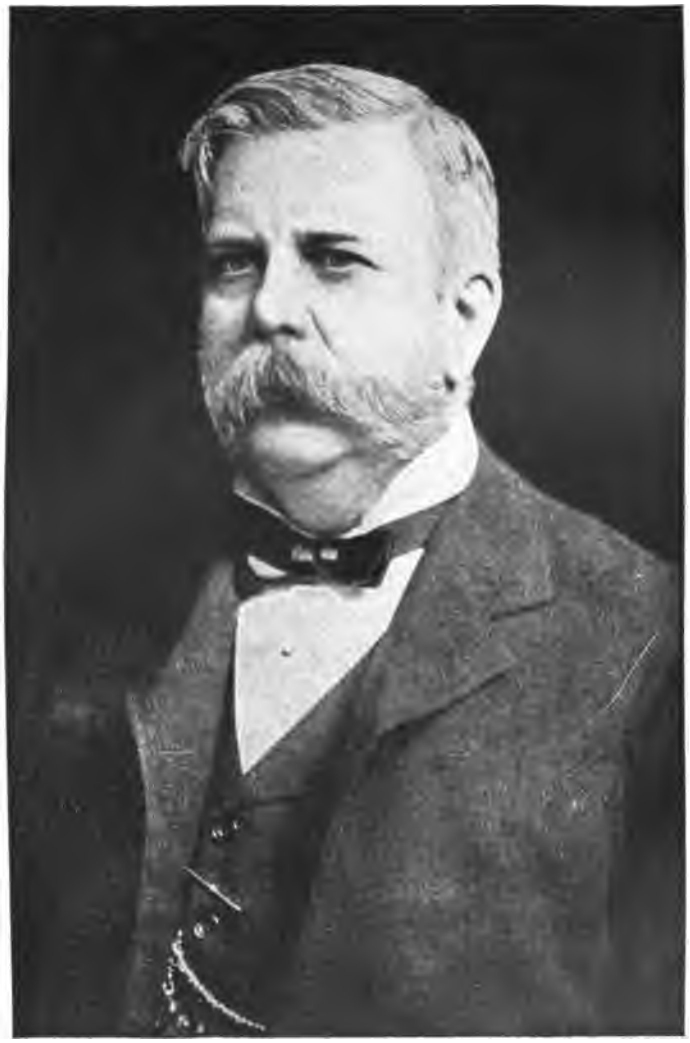
Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



GEORGE WESTINGHOUSE

Inventor of Westinghouse Air Brake and Numerous Other Electrical and Mechanical Devices. Pioneer in Introducing Alternating Current Machinery in America.

Cyclopedia
of
Engineering

A General Reference Work on
STEAM BOILERS, PUMPS, ENGINES, AND TURBINES, GAS AND OIL ENGINES,
AUTOMOBILES, MARINE AND LOCOMOTIVE WORK, HEATING AND
VENTILATING, COMPRESSED AIR, REFRIGERATION, DYNAMOS, MOTORS, ELECTRIC WIRING, ELECTRIC LIGHTING, ELEVATORS, ETC.

Editor-in-Chief
LOUIS DERR, M. A., S. B.
PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Assisted by a Staff of
CONSULTING ENGINEERS, TECHNICAL EXPERTS, AND DESIGNERS OF THE
HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

SEVEN VOLUMES

CHICAGO
AMERICAN TECHNICAL SOCIETY
1910

COPYRIGHT, 1902, 1903, 1904, 1906, 1907 1909
BY
AMERICAN SCHOOL OF CORRESPONDENCE

COPYRIGHT, 1902, 1903, 1904, 1906, 1907, 1909
BY
AMERICAN TECHNICAL SOCIETY

Entered at Stationers' Hall, London
All Rights Reserved

143134
JUN 13 1910
TB
.AM3
4

388938

Editor-in-Chief

LOUIS DERR, M. A., S. B.

Professor of Physics, Massachusetts Institute of Technology

Authors and Collaborators

LIONEL S. MARKS, S. B., M. M. E.
Assistant Professor of Mechanical Engineering, Harvard University
American Society of Mechanical Engineers

◆

LLEWELLYN V. LUDY, M. E.
Professor of Mechanical Engineering, Purdue University
American Society of Mechanical Engineers

◆

LUCIUS I. WIGHTMAN, E. E.
Electrical and Mechanical Engineer, Ingersoll-Rand Co., New York

◆

FRANCIS B. CROCKER, E. M., Ph. D.
Head of Department of Electrical Engineering, Columbia University, New York
Past President, American Institute of Electrical Engineers

◆

CHARLES L. GRIFFIN, S. B.
Assistant Engineer, the Solvay-Process Co.
American Society of Mechanical Engineers

◆

VICTOR C. ALDERSON, D. Sc.
President, Colorado School of Mines
Formerly Dean, Armour Institute of Technology

◆

WALTER S. LELAND, S. B.
Assistant Professor of Naval Architecture, Massachusetts Institute of Technology
American Society of Naval Architects and Marine Engineers

Authors and Collaborators—Continued

CHARLES L. HUBBARD, S. B., M. E.
Consulting Engineer on Heating, Ventilating, Lighting, and Power

◆

ARTHUR L. RICE, M. M. E.
Editor, *The Practical Engineer*

◆

WALTER B. SNOW, S. B.
Formerly Mechanical Engineer, B. F. Sturtevant Co.
American Society of Mechanical Engineers

◆

HUGO DIEMER, M. E.
Professor of Mechanical Engineering, Pennsylvania State College
American Society of Mechanical Engineers

◆

SAMUEL S. WYER, M. E.
American Society of Mechanical Engineers
Author of "Gas-Producers and Producer Gas"

◆

WILLIAM G. SNOW, S. B.
Steam Heating Specialist
American Society of Mechanical Engineers

◆

GLENN M. HOBBS, Ph. D.
Secretary, American School of Correspondence
Formerly Instructor in Physics, University of Chicago
American Physical Society

◆

LOUIS DERR, M. A., S. B.
Professor of Physics, Massachusetts Institute of Technology

◆

JOHN H. JALLINGS
Mechanical Engineer and Elevator Expert

◆

HOWARD MONROE RAYMOND, B. S.
Dean of Engineering, and Professor of Physics, Armour Institute of Technology

Authors and Collaborators—Continued

WILLIAM T. McCLEMENT, A. M., D. Sc.
Head of Department of Botany, Queen's University, Kingston, Canada

◆

GEORGE C. SHAAD, E. E.
Head of Department of Electrical Engineering, University of Kansas

◆

GEORGE L. FOWLER, A. B., M. E.
Consulting Engineer
American Society of Mechanical Engineers

◆

RALPH H. SWEETSER, S. B.
Superintendent, Columbus Iron & Steel Co.
American Institute of Mining Engineers

◆

CHARLES E. KNOX, E. E.
Consulting Electrical Engineer
American Institute of Electrical Engineers

◆

MILTON W. ARROWOOD
Graduate, United States Naval Academy
Refrigerating and Mechanical Engineer, with the Triumph Ice Machine Company

◆

R. F. SCHUCHARDT, B. S.
Testing Engineer, Commonwealth Edison Co., Chicago

◆

WILLIAM S. NEWELL, S. B.
With Bath Iron Works
Formerly Instructor, Massachusetts Institute of Technology

◆

GEORGE F. GEBHARDT, M. E., M. A.
Professor of Mechanical Engineering, Armour Institute of Technology

◆

HARRIS C. TROW, S. B., ***Managing Editor***
Editor-in-Chief, Textbook Department, American School of Correspondence
American Institute of Electrical Engineers

Authorities Consulted

THE editors have freely consulted the standard technical literature of Europe and America in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known treatises should be in the library of every engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

JAMES AMBROSE MOYER, S. B., A. M.

Member of The American Society of Mechanical Engineers; American Institute of Electrical Engineers, etc.; Engineer, Westinghouse, Church, Kerr & Co.
Author of "The Steam Turbine," etc.

◆

E. G. CONSTANTINE

Member of the Institution of Mechanical Engineers; Associate Member of the Institution of Civil Engineers.
Author of "Marine Engineers."

◆

C. W. MacCORD, A. M.

Professor of Mechanical Drawing, Stevens Institute of Technology.
Author of "Movement of Slide Valves by Eccentrics."

◆

CECIL H. PEABODY, S. B.

Professor of Marine Engineering and Naval Architecture, Massachusetts Institute of Technology.
Author of "Thermodynamics of the Steam Engine," "Tables of the Properties of Saturated Steam," "Valve Gears to Steam Engines," etc.

◆

FRANCIS BACON CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University; Past President American Institute of Electrical Engineers.
Author of "Electric Lighting," "Practical Management of Dynamos and Motors."

◆

SAMUEL S. WYER

Mechanical Engineer; American Society of Mechanical Engineers.
Author of "Treatise on Producer Gas and Gas-Producers," "Catechism on Producer Gas."

◆

E. W. ROBERTS, M. E.

Member, American Society of Mechanical Engineers.
Author of "Gas-Engine Handbook," "Gas Engines and Their Troubles," "The Automobile Pocket-book," etc.

Authorities Consulted—Continued

GARDNER D. HISCOX, M. E.

Author of "Compressed Air," "Gas, Gasoline, and Oil-Engines," "Mechanical Movements," "Horseless Vehicles, Automobiles, and Motor-Cycles," "Hydraulic Engineering," "Modern Steam Engineering," etc.

❧

EDWARD F. MILLER

Professor of Steam Engineering, Massachusetts Institute of Technology.
Author of "Steam Boilers."

❧

ROBERT M. NEILSON

Associate Member, Institution of Mechanical Engineers; Member of Cleveland Institution of Engineers; Chief of the Technical Department of Richardsons, Westgarth and Co., Ltd.
Author of "The Steam Turbine."

❧

ROBERT WILSON

Author of "Treatise on Steam Boilers," "Boiler and Factory Chimneys," etc.

❧

CHARLES PROTEUS STEINMETZ

Consulting Engineer, with the General Electric Co.; Professor of Electrical Engineering, Union College.
Author of "The Theory and Calculation of Alternating-Current Phenomena," "Theoretical Elements of Electrical Engineering," etc.

❧

JAMES J. LAWLER

Author of "Modern Plumbing, Steam and Hot-Water Heating."

❧

WILLIAM F. DURAND, Ph. D.

Professor of Marine Engineering, Cornell University.
Author of "Resistance and Propulsion of Ships," "Practical Marine Engineering."

❧

HORATIO A. FOSTER

Member, American Institute of Electrical Engineers; American Society of Mechanical Engineers; Consulting Engineer.
Author of "Electrical Engineer's Pocket-book."

❧

ROBERT GRIMSHAW, M. E.

Author of "Steam Engine Catechism," "Boiler Catechism," "Locomotive Catechism," "Engine Runners' Catechism," "Shop Kinks," etc.

❧

SCHUYLER S. WHEELER, D. Sc.

Electrical Expert of the Board of Electrical Control, New York City; Member American Societies of Civil and Mechanical Engineers.
Author of "Practical Management of Dynamos and Motors."

Authorities Consulted—Continued

J. A. EWING, C. B., LL. D., F. R. S.

Member, Institute of Civil Engineers; formerly Professor of Mechanism and Applied Mechanics in the University of Cambridge; Director of Naval Education.

Author of "The Mechanical Production of Cold," "The Steam Engine and Other Heat Engines."

◆

LESTER G. FRENCH, S. B.

Mechanical Engineer.

Author of "Steam Turbines."

◆

ROLLA C. CARPENTER, M. S., C. E., M. M. E.

Professor of Experimental Engineering, Cornell University; Member of American Society Heating and Ventilating Engineers; Member American Society Mechanical Engineers.

Author of "Heating and Ventilating Buildings."

◆

J. E SIEBEL

Director, Zymotechnic Institute, Chicago.

Author of "Compend of Mechanical Refrigeration."

◆

WILLIAM KENT, M. E.

Consulting Engineer; Member of American Society of Mechanical Engineers, etc.

Author of "Strength of Materials," "Mechanical Engineer's Pocket-book," etc.

◆

WILLIAM M. BARR

Member American Society of Mechanical Engineers.

Author of "Boilers and Furnaces," "Pumping Machinery," "Chimneys of Brick and Metal," etc.

◆

WILLIAM RIPPER

Professor of Mechanical Engineering in the Sheffield Technical School; Member of the Institute of Mechanical Engineers.

Author of "Machine Drawing and Design," "Practical Chemistry," "Steam," etc.

◆

J. FISHER-HINNEN

Late Chief of the Drawing Department at the Oerlikon Works.

Author of "Continuous Current Dynamos."

◆

SYLVANUS P. THOMPSON, D. Sc., B. A., F. R. S., F. R. A. S.

Principal and Professor of Physics in the City and Guilds of London Technical College.

Author of "Electricity and Magnetism," "Dynamo-Electric Machinery," etc.

◆

ROBERT H. THURSTON, C. E., Ph. B., A. M., LL. D.

Director of Sibley College, Cornell University.

Author of "Manual of the Steam Engine," "Manual of Steam Boilers," "History of the Steam Engine," etc.

Authorities Consulted—Continued

JOSEPH G. BRANCH, B. S., M. E.

Chief of the Department of Inspection, Boilers and Elevators; Member of the Board of Examining Engineers for the City of St. Louis.

Author of "Stationary Engineering," "Heat and Light from Municipal and Other Waste," etc.

◆

JOSHUA ROSE, M. E.

Author of "Mechanical Drawing Self Taught," "Modern Steam Engineering," "Steam Boilers," "The Slide Valve," "Pattern Maker's Assistant," "Complete Machinist," etc.

◆

CHARLES H. INNES, M. A.

Lecturer on Engineering at Rutherford College.

Author of "Air Compressors and Blowing Engines," "Problems in Machine Design," "Centrifugal Pumps, Turbines, and Water Motors," etc.

◆

GEORGE C. V. HOLMES

Whitworth Scholar; Secretary of the Institute of Naval Architects, etc.

Author of "The Steam Engine."

◆

FREDERIC REMSEN HUTTON, E. M., Ph. D.

Emeritus Professor of Medical Engineering in Columbia University; Past Secretary and President of American Society of Mechanical Engineers.

Author of "The Gas Engine," "Mechanical Engineering of Power Plants," etc.

◆

MAURICE A. OUDIN, M. S.

Member of American Institute of Electrical Engineers.

Author of "Standard Polyphase Apparatus and Systems."

◆

WILLIAM JOHN MACQUORN RANKINE, LL. D., F. R. S. S.

Civil Engineer; Late Regius Professor of Civil Engineering in University of Glasgow.

Author of "Applied Mechanics," "The Steam Engine," "Civil Engineering," "Useful Rules and Tables," "Machinery and Mill Work," "A Mechanical Textbook."

◆

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, Massachusetts Institute of Technology; Member of American Institute of Electrical Engineers.

Author of "A Textbook on Electro-Magnetism and the Construction of Dynamos," "Alternating Currents and Alternating-Current Machinery."

◆

A. E. SEATON

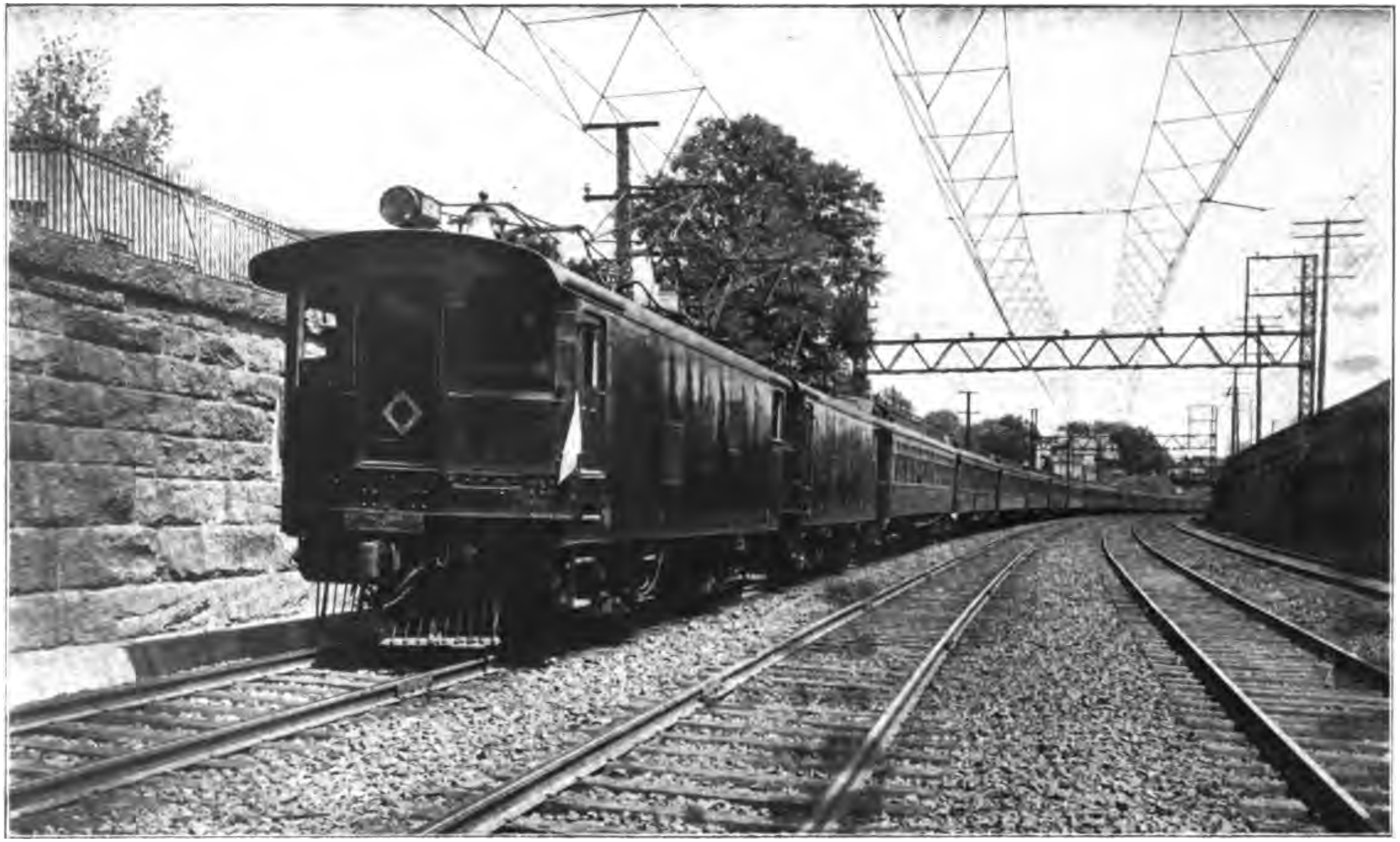
Author of "A Manual of Marine Engineering."

◆

WILLIAM C. UNWIN, F. R. S., M. Inst. C. E.

Professor of Civil and Mechanical Engineering, Central Technical College, City and Guilds of London Institute, etc.

Author of "Machine Design," "The Development and Transmission of Power," etc.



SINGLE-PHASE LOCOMOTIVES HAULING FAST PASSENGER TRAIN ON THE NEW YORK, NEW HAVEN, AND HARTFORD RAILWAY
Note the Line Construction.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.

Foreword

THE rapid advances made in recent years in all lines of engineering, as seen in the evolution of improved types of machinery, new mechanical processes and methods, and even new materials of workmanship, have created a distinct necessity for an authoritative work of general reference embodying the accumulated results of modern experience and the latest approved practice. The Cyclopedia of Engineering is designed to fill this acknowledged need.

¶ The aim of the publishers has been to create a work which, while adequate to meet all demands of the technically trained expert, will appeal equally to the self-taught practical man, who may have been denied the advantages of training at a resident technical school. The Cyclopedia not only covers the fundamentals that underlie all engineering, but places the reader in direct contact with the experience of teachers fresh from practical work, thus putting him abreast of the latest progress and furnishing him that adjustment to advanced modern needs and conditions which is a necessity even to the technical graduate.

¶ The Cyclopedia of Engineering is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching the principles and practice of Engineering in its different branches.

¶ The success which the American School of Correspondence has attained as a factor in the machinery of modern technical and scientific education is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing, as they do, the best ideas and methods of a large number of different authors, each an acknowledged authority in his work—they are by no means an experiment, but are, in fact, based on what has proved itself to be the most successful method yet devised for the education of the busy man. The formulæ of the higher mathematics have been avoided as far as possible, and every care exercised to elucidate the text by abundant and appropriate illustrations.

¶ Numerous examples for practice are inserted at intervals; these, with the text questions, help the reader to fix in mind the essential points, thus combining the advantages of a text-book with those of a reference work.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the publishers will feel that its mission has been accomplished.

¶ Grateful acknowledgment is due the corps of authors and collaborators—engineers and designers of wide practical experience, and teachers of well-recognized ability—without whose co-operation this work would have been impossible.

Table of Contents

VOLUME IV

LOCOMOTIVE BOILERS AND ENGINES . *By L. V. Ludy*† Page *11

Historical Development—Classification of Locomotives—Compound Locomotive—Locomotive Boilers—Classification—Fire-Box—Flues—Stay-Bolts—Grates—Ash Pans—Brick Arches—Smoke Box—Steam Pipes—Exhaust Nozzle—Netting—Diaphragm—Draft Pipes—Draft—Rate of Combustion—Spark Losses—Effect of Pressures—Heating Surface—Superheater—Locomotive Boiler Design—Locomotive Engine—Lead—Lap—Clearance—Valve Motion—Valve Gears—Setting Locomotive Valves—Running Gear—Locomotive Frames—Locomotive Trucks—The Tender—The Design of the Locomotive—Safety Valves—Injectors—Whistles—Gauges—Blower—Throttle Valve—Dry Pipes—Lubricator—Railway Signalling—Semaphores—Block System—Locomotive Operation—Learning the Road—Handling Trains—Inspection—Cleaning—Repairs—Emergencies (Broken Side Rods, Connecting Rods, Driving Springs, Low Water, Foaming, Broken Steam Chest, etc.)—Train Rules—Time Tables

THE AIR-BRAKE . . . . *By L. V. Ludy* Page 165

Early Forms of Brake—Straight Air-Brake—Plain Automatic Air-Brake—Vacuum Brake—Buffer Brakes—Interchangeable Brake System—Westinghouse Air-Brake System—Operation—Air Pump—Main Reservoir—Air Pump Governor—Engineer's Brake-Valve—Quick-Action Triple Valve—Pressure-Retaining Valve—High-Speed Brake—Manipulation—Automatic Brake Valve—Independent Brake Valve—Reducing Valve—Pump Governor—New York Air-Brake—Foundation Brake Gear—Leverage—Train Air Signal System—Use and Care of Air-Brake Equipment—Air-Brakes on Electric Cars

THE SINGLE-PHASE ELECTRIC RAILWAY . *By H. C. Trow* Page 277

Introduction—Single-Phase System—Commutator Type, Single-Phase Motor—Transformers—Trolley Suspension—Multiple-Unit Control

CENTRAL STATION ENGINEERING . *By R. F. Schuchardt* Page 297

Development of Central Station Idea—Edison Constant-Potential System—Three-Wire D. C. System—A. C. Systems—Development of Water Powers—High-Voltage Polyphase Systems

ELEVATORS . . . . *By J. H. Jallings* Page 325

Steam Elevators—Elevator Engines—Hydraulic Elevators—Electric Elevators—Motors—Controllers—Electric Limit Switches—Elevator Accessories

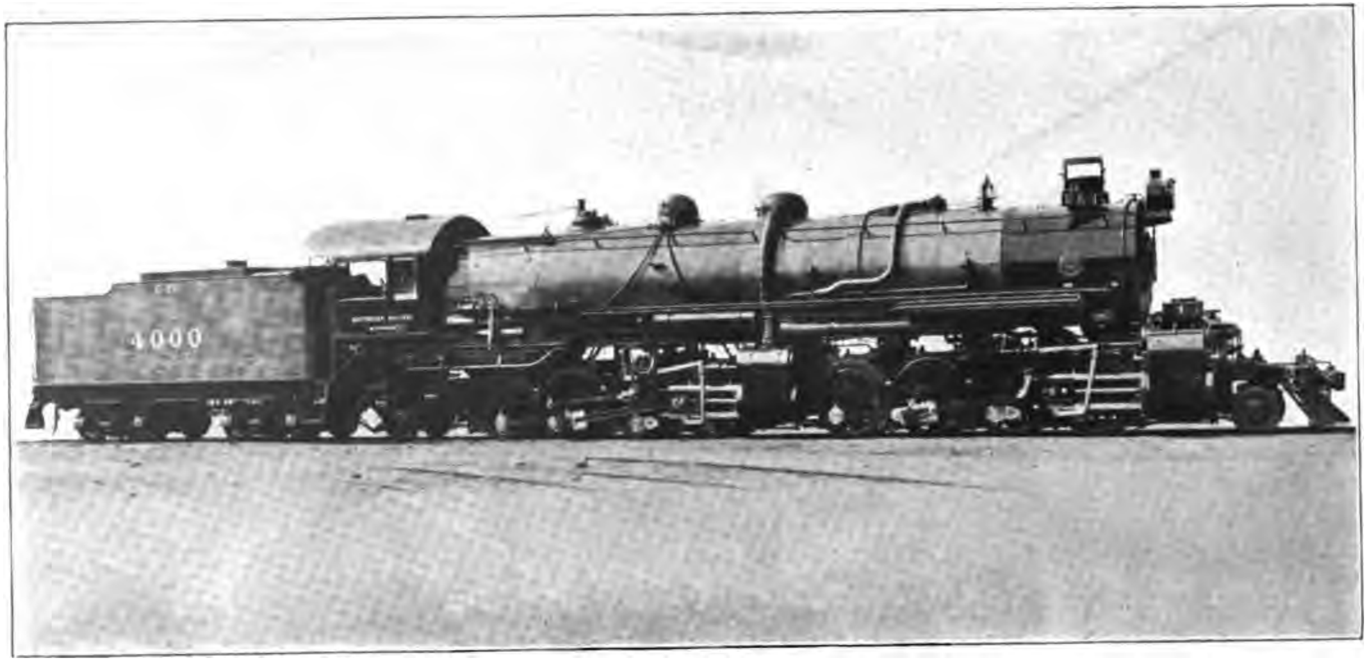
REVIEW QUESTIONS . . . . Page 375

INDEX . . . . Page 387

---

*For page numbers, see foot of pages.

†For professional standing of authors, see list of Authors and Collaborators at front of volume.



MALLET ARTICULATED COMPOUND LOCOMOTIVE
American Locomotive Co.

LOCOMOTIVE BOILERS AND ENGINES

PART I

HISTORICAL DEVELOPMENT OF THE LOCOMOTIVE

The first locomotive engine designed to run upon rails was constructed in 1803, under the direction of Richard Trevithick, a Cornish mine captain in South Wales. Though crudely and peculiarly made, it possessed all of the characteristics of the modern locomotive with the exception of the multi-tubular boiler. The locomotive had a return-flue boiler 60 inches long, and two pairs of driving wheels—each 52 inches in diameter. The power was furnished by one cylinder, 54 inches long and 8 inches in diameter. The exhaust steam from the cylinder was conducted to the smoke-stack where it aided in creating a draft on the fire. This engine, shown in Fig. 1, made several trips of nine miles each, running about five miles per

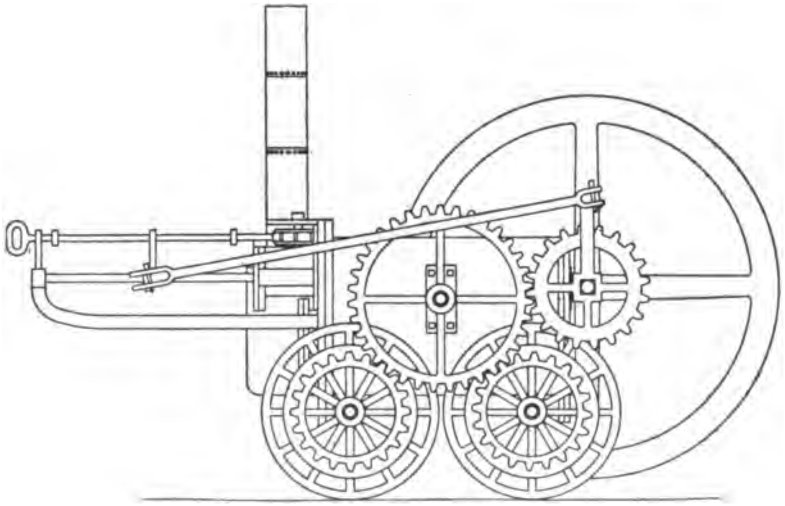


Fig. 1. Trevithick's Locomotive.

Copyright, 1909, by American School of Correspondence.

hour and carrying about two tons. Although the machine was a commercial failure, yet from a mechanical standpoint, it was a great success.

After the development of the Trevithick locomotive, numerous experiments were tried out and many engineers were working on a new design. As a consequence, many very crude but interesting locomotives were developed. The principal objection raised against the most of them was in reference to the complicated parts of the mechanism. Having had no previous experience to direct them, they failed to see that the fewer and simpler the parts of the machine, the better. It was not until about 1828, when the *Rocket*, as shown in Fig. 2, was built under the supervision of Robert Stephenson, that anything of note was accomplished. The Rocket, in a competition speed test, without carrying any load, ran at the rate of 29½ miles per hour. With a car carrying thirty passengers, it attained a speed of 28 miles per hour. The construction of the Rocket was a step in the right direction, since it contained fewer and simpler parts. It had an appearance similar to the modern locomotive, having a multitubular boiler, induced draft by means of the exhaust steam, and a

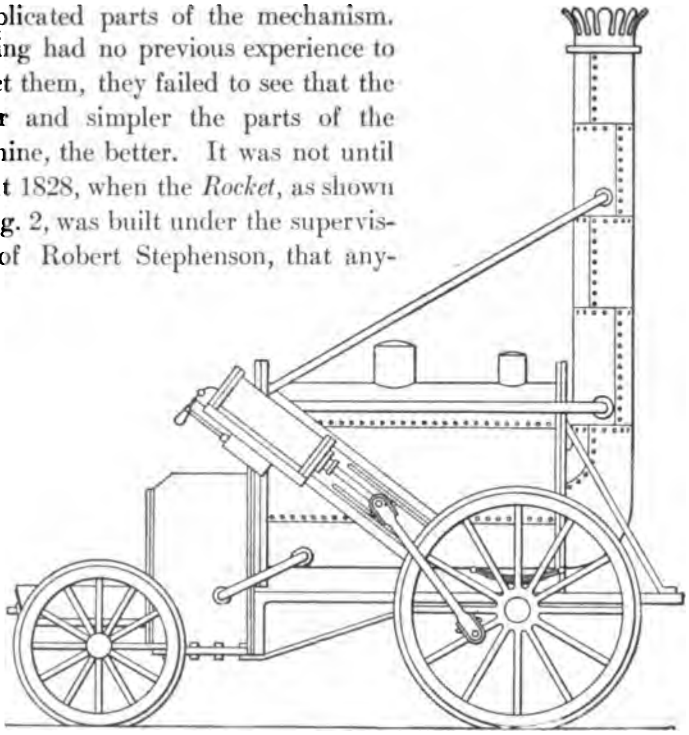


Fig. 2. The Rocket.

direct connection between the piston rod and the crank pin secured to the driving wheel. The cylinder was inclined and the proportions were very peculiar as compared with the modern locomotive, yet much had been gained by this advancement.

While these things were being accomplished in England, the fact must be noted that agitation in favor of railroad building in America was being carried on with zeal and success. Much of the machinery for operating the American railroads was being designed and built by American engineers, so it is quite generally believed that railroad and locomotive building in America would not have been very much delayed had there never been a Watt or a Stephenson.

The first railroad opened to general traffic was the Baltimore & Ohio, which was chartered in 1827, a portion being opened for business in 1830. About the same time, the South Carolina Road was built. The board of directors of this road were concerned with what kind of power to use, namely, horse-power or steam engines. After much deliberation, it was finally decided to use a steam-propelled locomotive.

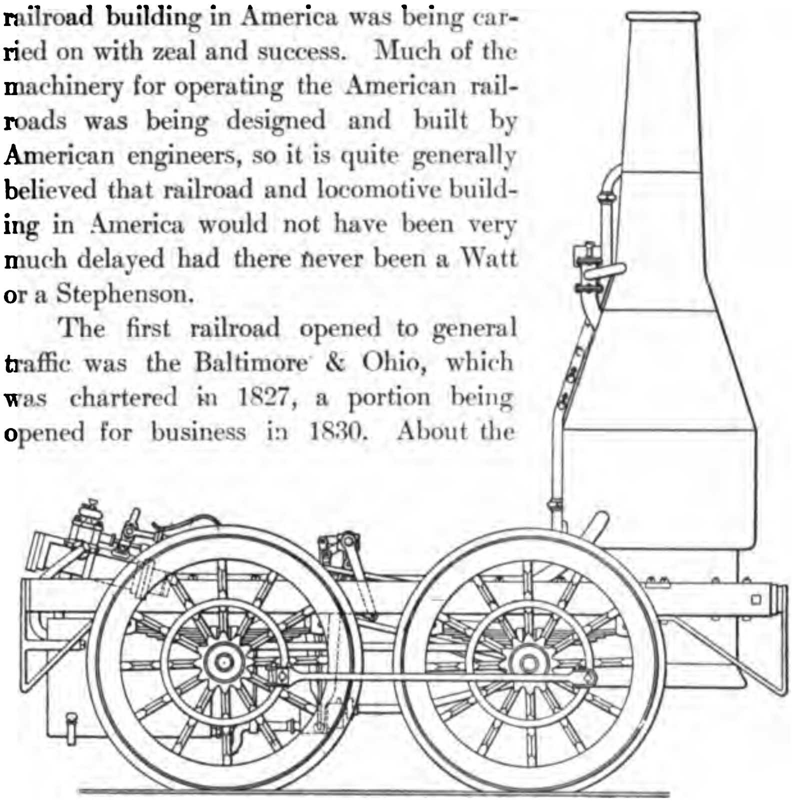


Fig. 3. The Best Friend of Charleston.

The history of this period is interesting. The first steam locomotive built in America was the *Best Friend of Charleston,* illustrated in Fig. 3. One year previous to the building of this locomotive, an

English locomotive called *Stourbridge Lion* was imported by the Delaware-Hudson Canal Co. It was tried near Homesdale. A celebrated American engineer by the name of Horatio Allen, made a number of trial trips on this locomotive and pronounced it too heavy for the American roadbeds and bridges; so it was that the Best Friend of Charleston, an American locomotive constructed in 1830, gave the first successful service in America. The Best Friend of Charleston was a four-wheeled engine having two inclined cylinders. The wheels were constructed of iron hubs with wooden spokes and wooden fellows, having iron tires shrunk on in the usual way. A vertical boiler was employed and rested upon an extension of the frame which was placed between the four wheels. The cylinders, two in number, were each 6 inches in diameter and had a common stroke of 16 inches. The wheels were 4½ feet in diameter. The total weight of the locomotive was about 10,000 pounds. Assuming power by present methods, it would develop about 12 horse-power while running at a speed of 20 miles per hour and using a steam pressure of 50 pounds.

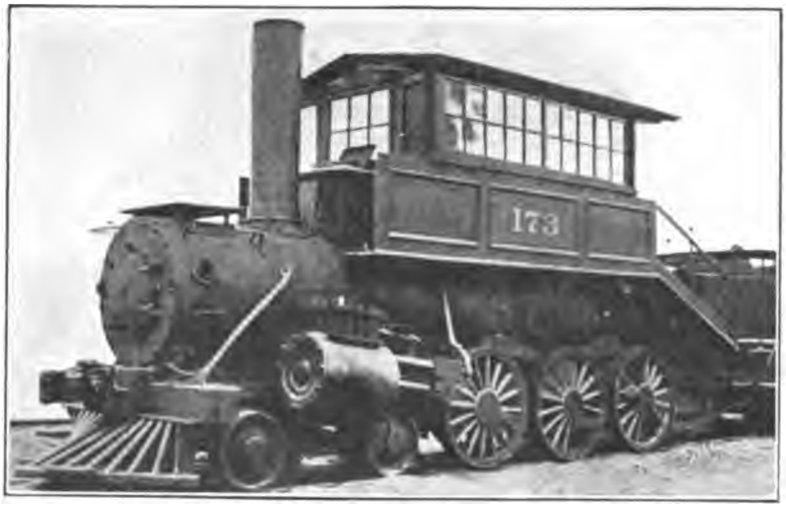


Fig. 4a. Hayes 10-Wheeler.

The Baltimore & Ohio Railroad was the leader for a number of years in the development of the locomotive. Among the earlier designs brought out by this road was an 8-wheeled engine known as the *Camel-Back,* so-called from its appearance, and frequently spoken of as the *Winans,* as its design was developed in 1844 by Ross Winans, a prominent locomotive builder of a half century ago.

The illustration shown in Fig. 4*a* represents the *Hayes 10-Wheeler* with side rods removed, which was built after designs prepared in 1853 by Samuel J. Hayes of the B. & O. Fig. 4*b* is from an original drawing of one of the earlier types of the same engine and shows more of the details of construction. This locomotive is oftentimes improperly called the *Camel-Back* or *Winans* engine because of its close resemblance to the Winans. The name *Camel-Back,* as given to the Winans engine and also to the Hayes 10-Wheeler, was given on account of the peculiar appearance of the locomotive, which, in fact, did resemble a camel's humped back. This appearance was due to the fact that a large cab was placed on the central portion of the boiler, and also to the rapidly receding back end of the boiler. The weight of the Hayes 10-Wheeler is 77,100 pounds, of which 56,500 pounds are on the drivers and 20,060 pounds are on the front truck. The diameter of the front truck wheels is 28 inches and that of the drivers, 50 inches. The fire-box is 42¼ inches long and 59¼ inches wide. The boiler has a total heating surface of 1,176.91 square feet, 1,098 square feet of this amount being in the flues. There are 134 tubes 2¼ inches in diameter and 13 feet 11 inches long.

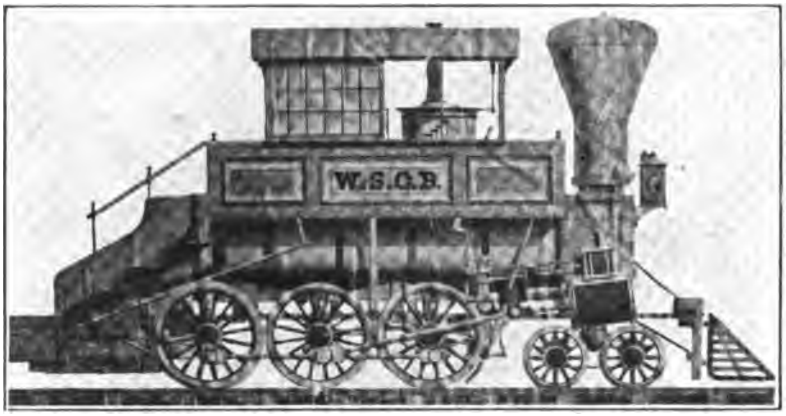


Fig. 4*b*. Hayes 10-Wheeler.

The Boston & Providence Railroad built several locomotives during the time the Winans locomotive was being developed. One of these, the *Daniel Nason,* illustrated in Fig. 5, was built in 1858. The Daniel Nason weighs 52,650 pounds, has 16 by 20 inch cylinders, 54-inch driving wheels, and 30-inch truck wheels. Steam pumps were used in feeding the boiler instead of the injectors. The top members of the frame are built up of rectangular sections, while for the bottom members, 4-inch tubes are used.

The prevailing thought in the early development of the locomotive was, that sufficient power could not be secured by depending upon the adhesion of the drivers to the rail; as a consequence many cog locomotives were developed and used. This was true on the old Jeffersonville, Madison & Indianpaolis Railroad at Madison, Indiana. A portion of the road at that point included a six per cent grade three miles long. From the opening of the road in 1848 until 1858, the grade was operated by cog locomotives. On the last-named date, there appeared a locomotive named the *Reuben Wells* which was destined to have both a very interesting and successful career.

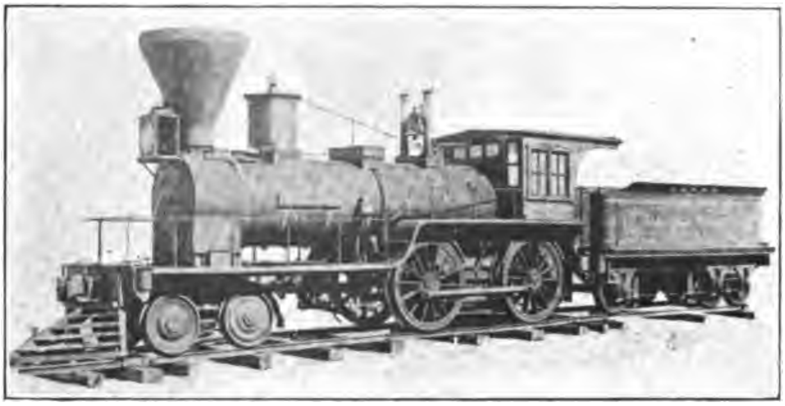


Fig. 5. The Daniel Nason.

The Reuben Wells, illustrated in Fig. 6, was designed by Mr. Reuben Wells, then a master mechanic of the road. It was built in the company's shops at Jeffersonville, Indiana, in July, 1858. The Reuben Wells has cylinders 20 × 24 inches, and five pairs of drivers each 49 inches in diameter, all being coupled. No front truck is used. The boiler is 56 inches in diameter and contains

201 two-inch flues 12 feet 2 inches in length. It has a heating surface in the fire-box of 116 square feet while that in the tubes is 1,262 square feet. It is what is commonly known as a *tank locomotive* since it carries the water and fuel upon the frame and wheels of the engine proper instead of upon a separate part, the tender. The total weight with fuel and water is 112,000 pounds. The tractive effort under a steam pressure of 100 pounds per square inch is about 21,818 pounds on a level road. After having been in service for a number of years, it was rebuilt with four instead of five pair of drivers and was shortened by the cutting off of a section at the

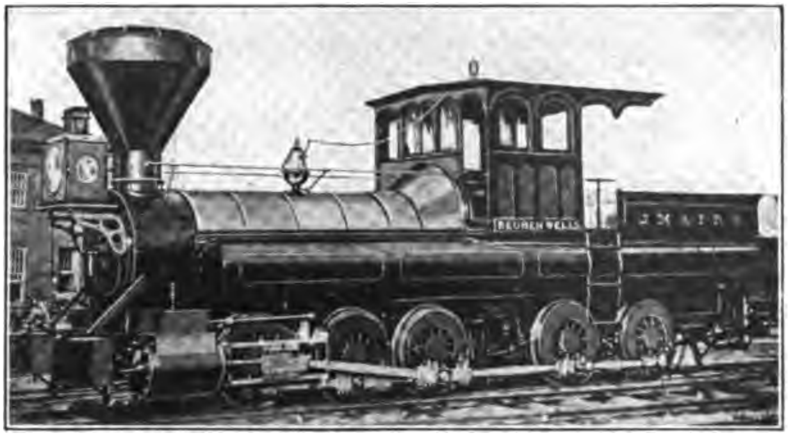


Fig. 6. The Reuben Wells.

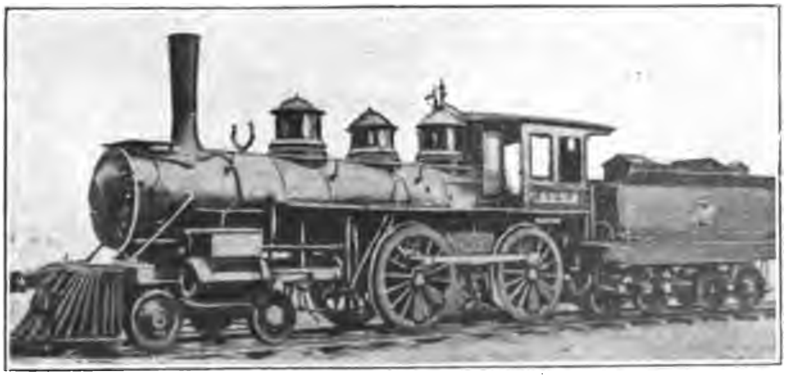


Fig. 7. American Type.

rear which had been used for coal and water. Sufficient water capacity was provided by placing a tank over the boiler.

The American type locomotive, illustrated in Fig. 7, is typical of the small sized engines of this construction which are now being rapidly replaced by other types. For a period of nearly fifty years, ending about 1895, the American type locomotive was more commonly used for passenger service than any other type.

A comparison of things with reference to size, weight, and color impresses their relative characteristics upon the mind. For this reason, the illustrations of the *Tornado* and the *Mallet* compound locomotives are given in Fig. 8 and Fig. 9, respectively, the former being an early development, and the latter the most recent heavy freight locomotive.

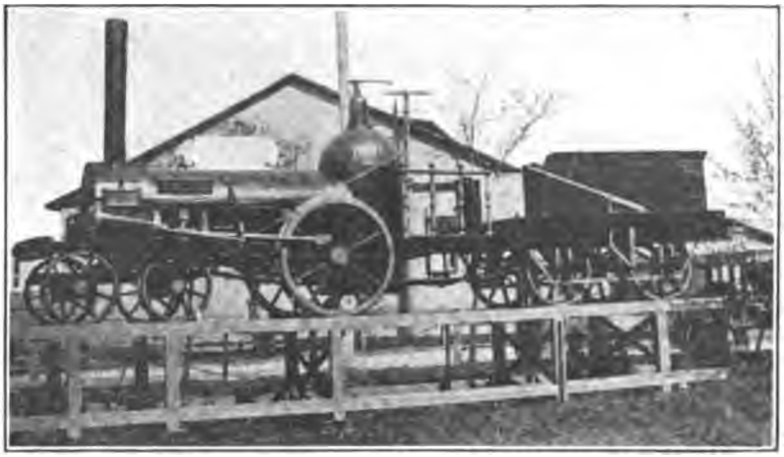


Fig. 8. The Tornado.

The Tornado was the second locomotive owned by one of the parent lines forming a part of the Seaboard Air Line Railroad. This locomotive was imported from England and put into service in March, 1840. It has two inclined cylinders 9 inches in diameter with a common stroke of 20 inches and a single pair of drivers 54 inches in diameter. The fire-box stands upright and is cylindrical in form, while the boiler proper is horizontal and but 34 inches in diameter. The steam is admitted to an exhaust from the cylinders by plain slide valves controlled by the *Hook* motion.

The Mallet compound locomotive marks one of the most successful attempts of the locomotive designer and builder. It surpasses anything thus far built in size and combination of new ideas in design. The one shown in the illustration was built for the Erie Railroad for heavy pushing service. It has a boiler diameter of 84 inches and carries a steam pressure of 215 pounds per square inch. The boiler contains 404 two and one-fourth inch flues 21 feet long. Its high-pressure and low-pressure cylinders are 25 and 39 inches in diameter, respectively, having a common stroke of 28 inches. The drivers, sixteen in number, are each 64 inches in diameter. The total weight on the drivers is 410,000 pounds. The boiler has a total heating surface of 5313.7 square feet, 4971.5 of this number being in the tubes and 342.2 in the fire-box. The fire-box is 126 inches long and 114 inches wide, giving 100 square feet of grate area. Its maximum tractive effort is 94,800 pounds.

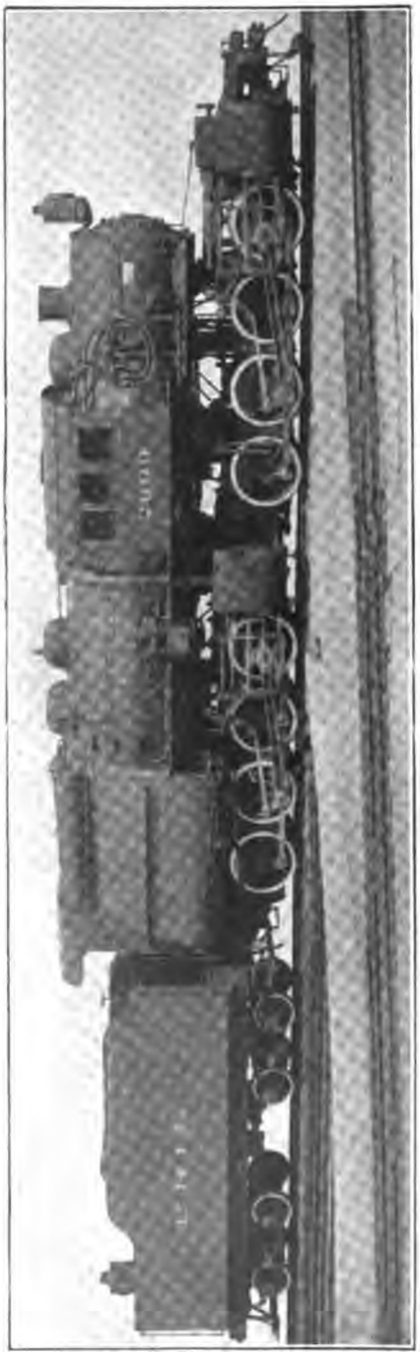


Fig. 9. Mallet Compound Locomotive.

It is of much interest to compare in a general way the developments of the locomotive in England and in America. The types differ in many respects, as shown in Table I.

TABLE I
*Comparison of English and American Locomotives

PARTS	ENGLISH	AMERICAN
Frames	Plate	Bar
Cylinders	Inside	Outside
Drivers	Not equalized	Equalized
Driver Centers	Wrought iron	Cast iron or steel
Fire-box	Copper	Steel
Tubes	Brass	Iron
Cab	Small	Large
Pilot	No	Yes
Reverse gear	Screw	Lever
Boiler	Small and low	Large and high

CLASSIFICATION OF LOCOMOTIVES

In order that a clear understanding may be had of the various types of locomotives, a classification is given according to wheel arrangement. In the Whyte system of classification, which is quite largely used, each set of trucks and driving wheels is grouped by number beginning at the pilot or front end of the engine. Thus, 260 means a Mogul, and 460, a 10-wheel engine. The first figure, 2, in 260 denotes that a 2-wheeled truck is used in front; the figure 6, that there are six coupled divers, three on each side; and the 0, that no trailing truck is used. This scheme gives both a convenient and easy method of classifying locomotives.

In Table II is given the classification of the locomotives used on American railroads.

The method may be further extended to include the weights of locomotives. The total weight is expressed in units of 1,000 pounds. Thus: A Pacific locomotive weighing 189,000 pounds would be classified as Type 462—189. If the locomotive is a compound, a letter C would be used instead of the dash. Thus: Type 462–C–189. If tanks are used instead of a separate tender, the letter T would be substituted for the dash. Thus: A tank locomotive having four driving wheels, a 4-wheel leading truck, and a 4-wheel rear truck, weighing 114,000 pounds would be classified as Type 444–T–114.

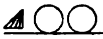
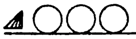
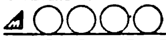
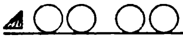
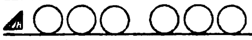
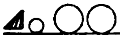
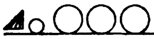
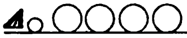
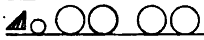
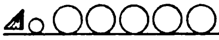
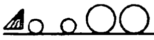
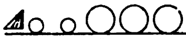
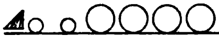
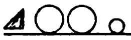
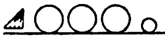
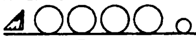
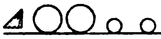
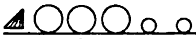
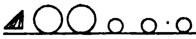
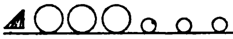
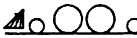
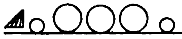
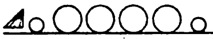
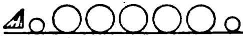
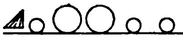
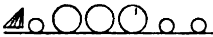
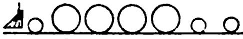
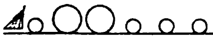
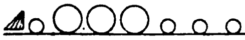
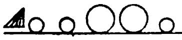
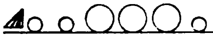
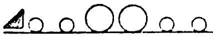
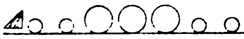
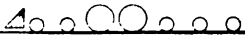
---

*The comparisons are not strictly true for every case but represent the conditions usually found.

TABLE II

Classification of Locomotives

[WHYTE'S SYSTEM]

040		4 Wheel
060		6 Wheel
080		8 Wheel
0440		Articulated
0660		Articulated
240		4 Coupled
260		Mogul
280		Consolidation
2440		Articulated
2100		Decapod
440		8 Wheel
460		10 "
480		12 "
042		4 Coupled and Trailing
062		6 " " "
082		8 " " "
044		Forney 4 Coupled
064		" 6 "
046		" 4 "
066		" 6 "
242		Columbia
262		Prairie
282		8 Coupled
2102		10 "
244		4 "
264		6 "
284		8 "
246		4 "
266		6 "
442		Atlantic
462		Pacific
444		4 Coupled Double Ender
464		6 " " "
446		4 " " "

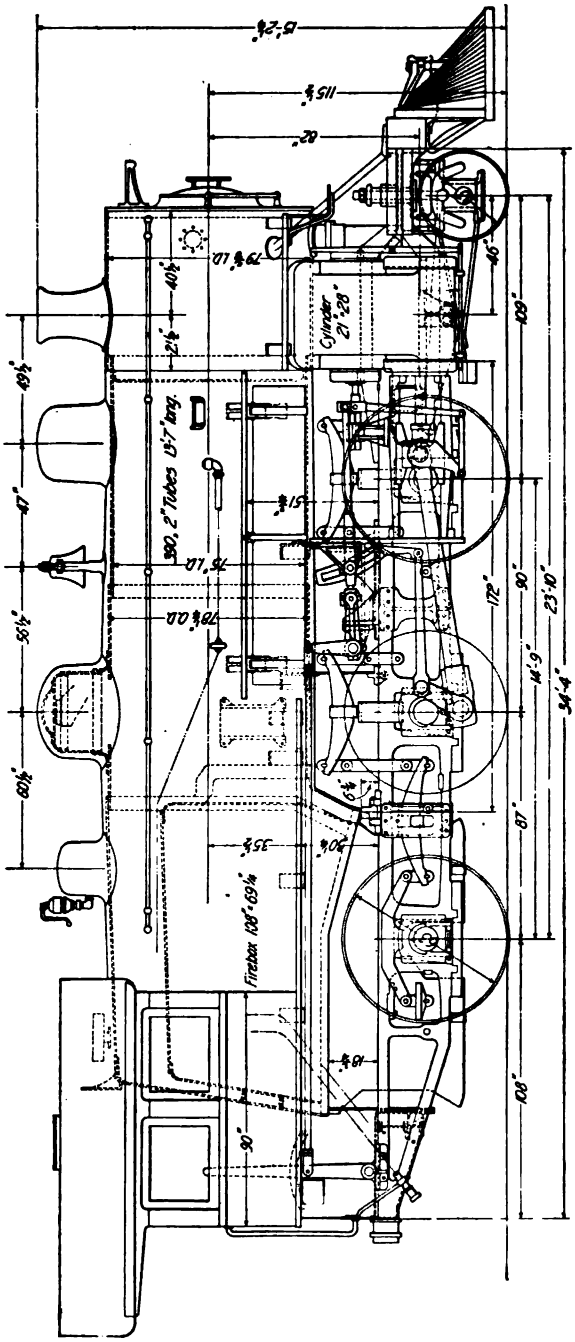


Fig. 10. Modern 260, or Mogul Type of Locomotive.

From the classification table given, it is apparent that there are a great many different types of locomotives in service. Only the more commonly used types will be discussed, which are as follows: 040, 060, 080, 260, 280, 440, 442, 460, and 462. The types 040, 060, and 080 are largely used for switching service. The 040 type is of the smallest proportions and weights, being found in small yards where only light work is required. The call for heavy duty was met by the 060 type. The fact that the 060 type, being much heavier, has a greater tractive effort and a correspondingly larger steaming capacity, has caused them to be used very extensively. The following figures will aid in giving an idea of their size and capacity:

Weight on drivers (pounds)	145,000 to 170,000
Diameter of cylinders (inches)	19 to 22
Stroke of piston (inches)	24 to 26
Diameter of driving wheels (inches)	50 to 56
Working steam pressure (pounds per square inch)	180 to 200

The demand for power, steadily increasing beyond that which could be secured by locomotives of the 060 type, created a new design known as the 8-wheel, or 080 type. This type is used in switching and pushing service and has about 171,000 pounds weight on drivers, cylinders 21 inches in diameter, stroke 28 inches, drivers 51 inches in diameter, and carries 175 to 200 pounds steam pressure. The switching engines of the 060 and 080 type were converted into high-class freight engines by adding two wheel trucks to each, thus developing the 260, or Mogul, and the 280, or Consolidation types.

The Mogul was primarily intended for freight service only, but it is sometimes used in heavy passenger service. The object of the design was to obtain greater tractive force on driving wheels than is possible to obtain with four drivers, as in the 440 type. Fig. 10 illustrates a modern 260, or Mogul type, giving its principal dimensions. This type was more generally used than any other before the increasing requirements of heavy freight service resulted in the development of the 280, or Consolidation type. It is profitable from the standpoint of economy in repairs in selecting the type of locomotive for any service, to use the minimum number of drive wheels possible within the limits of the necessary tractive power, although for freight service involving the handling of heavy trains on steep grades, the 280, or Consolidation type, is required. Where the requirements are

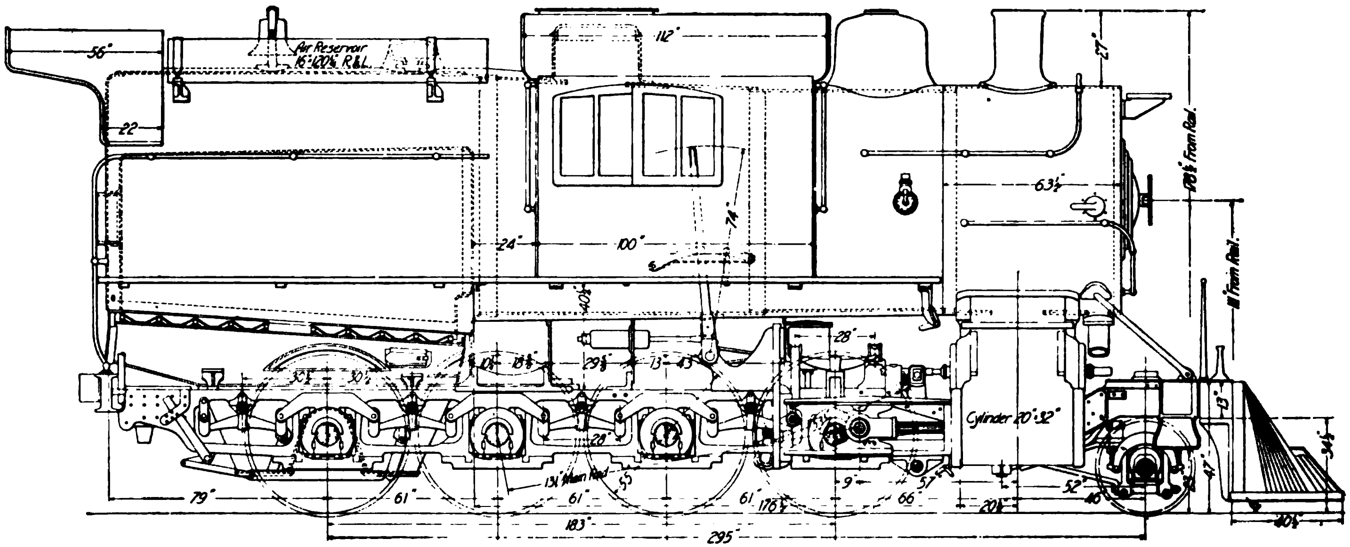


Fig. 11. A 280, or Consolidation Type of Locomotive.

not too severe, however, there is a large field for the Mogul type in freight service. Where a large axle load is permitted, the Mogul type may give sufficient hauling capacity to meet ordinary requirements in freight service on comparatively level roads. While not generally recommended for what may be called fast freight service, the 280, or Consolidation type, is sometimes used. Many Mogul locomotives are successfully handling such trains.

The 260 type provides a two-wheel leading truck with good guiding qualities and places a large percentage of the total weight on the driving wheels. A large number of locomotives of this type show an average of 87½ per cent of the total weight of the locomotive on the drivers. Boilers with sufficient capacity for moderate speed may be provided in this type; and with relatively small diameters of driving wheels, it will lend itself readily to wide variations in grates and fireboxes

The Consolidation locomotive, or 280 type, shown in Fig. 11, was designed, as has been mentioned, for hauling heavy trains over steep grades. It is perhaps more generally used as a high class freight engine than any other type so far developed. Locomotives of this type have been designed and built with total weights varying between 150,000 to 300,000 pounds.

The four most prominent types of passenger locomotives, namely, 440, 442, 460, and 462, have each been developed at different times and in successive order to meet the ever-increasing and changing demands. The 8-wheel or 440 type, commonly known as the *American type*, was for some time the favorite passenger locomotive, but as the demands for meeting the conditions of modern fast passenger service increased, a locomotive of new design was required. The conditions which were to be met were *sustained high speed* and *regular service*. This did not mean bursts of high speed under favorable conditions with a light train running as an extra or special with clear orders, but it meant rather the more exacting requirements of regular service.

Where regular train service had to be sustained day after day at a schedule of 50 miles per hour, it required reserve power to meet the unfavorable conditions of the weather and for an occasional extra car in the train. For such exacting demands, much steam is required and ample heating and grate surface must be provided. In the 440

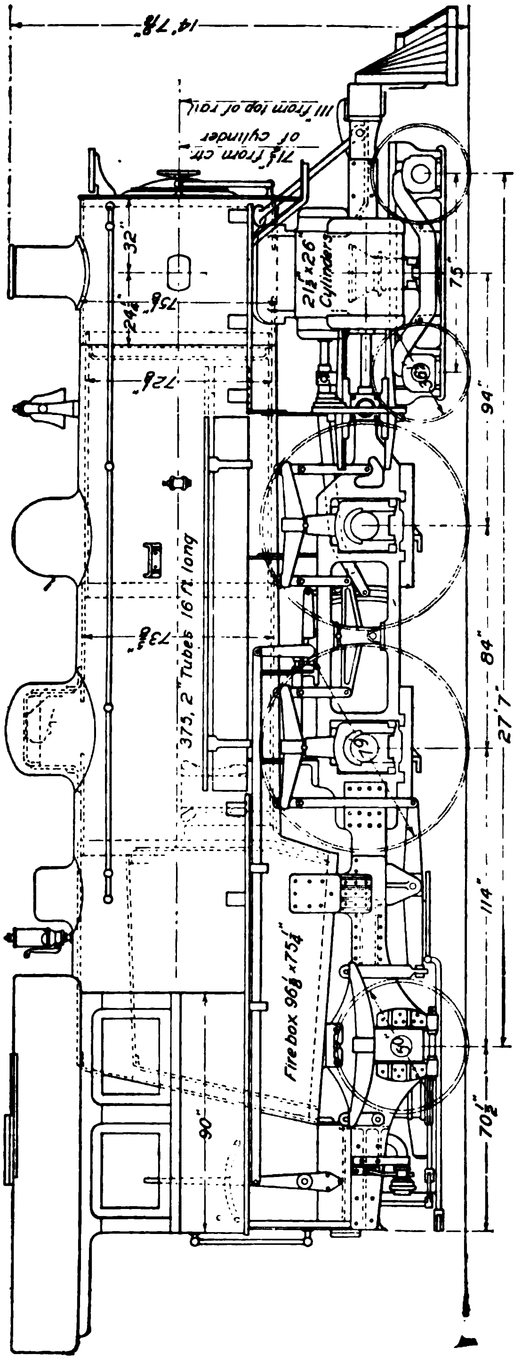


Fig. 12. A 442, or Atlantic Type of Locomotive.

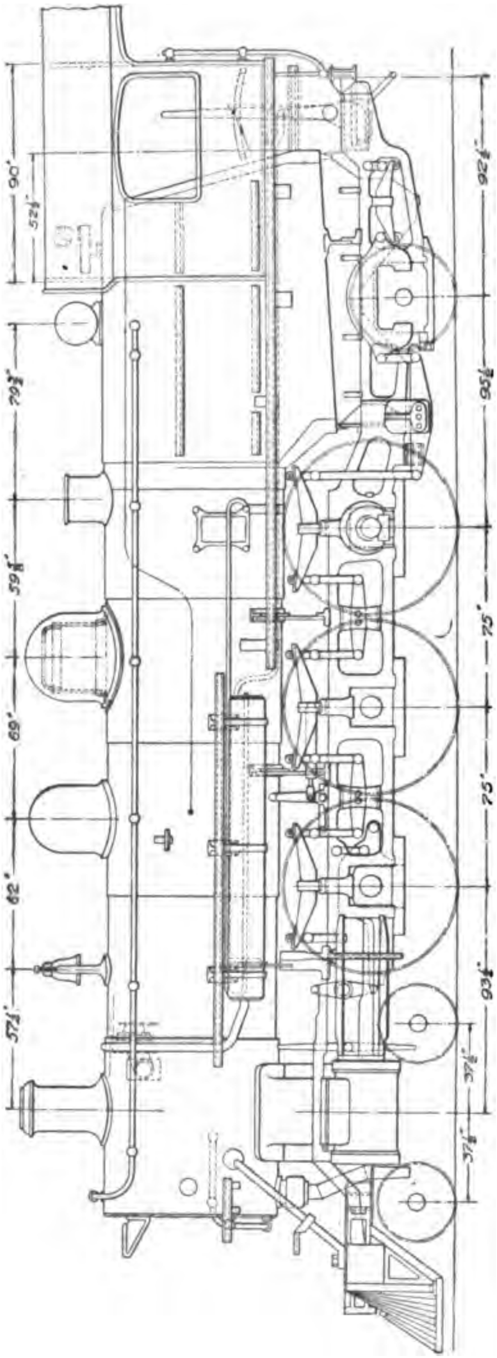
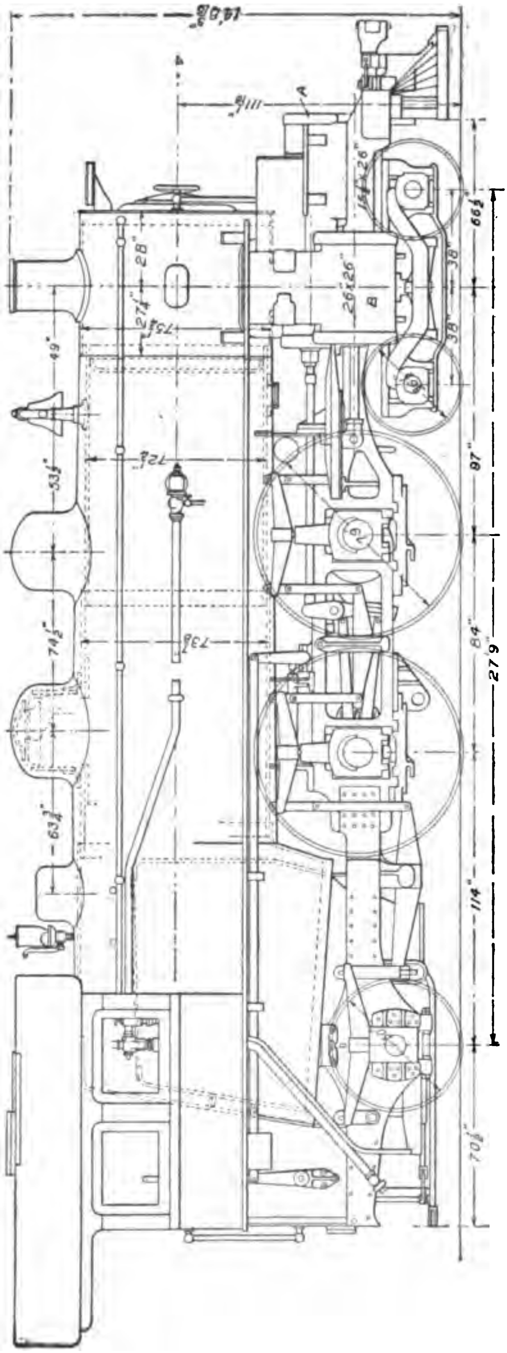


Fig. 13. A 462, or Pacific Type of Locomotive for Very Heavy Passenger Service.

type with a 4-wheel leading truck and four driving wheels without a trailing truck, the boiler capacity is limited. Not only is the heating surface also limited but the grate area as well, because the grates must be placed between the driving wheels. The desirability of larger boilers and wider grates than the distance between the wheels in the 440 type will permit, led to a ready acceptance of the 442, or Atlantic type locomotive, as shown in Fig. 12. The 442 type combines a 4-wheel leading truck, providing good guiding qualities, and four coupled driving wheels having a starting capacity sufficient for trains of moderate weight, and a trailing truck. The use of the trailing truck permits the extension of the grates beyond the driving wheels thus obtaining a much larger grate area. This wheel arrangement also permits the use of a deep as well as a wide fire-box which is especially advantageous in the burning of bituminous coal. It also gives a much greater depth at the front or throat of the fire-box, which is very important.

As modern passenger service increased and heavier trains had to be drawn, four driving wheels would not give sufficient starting power. Because of the heating surface and grate area being limited by the same factors as mentioned in the 440 type, another type, the 462, or Pacific type, came into favor. As this type was called upon to pull the heaviest passenger trains, much power was required even under very favorable conditions. For such trains, a locomotive having a combination of large cylinders, heavy tractive weight, and large boiler capacity is required. The Pacific type meets these requirements in a very successful way. From a study of Fig. 13, which illustrates such a locomotive, it is obvious that the 462 type differs from the general design of the Atlantic type only in the addition of another pair of driving wheels. This, however, makes possible a much heavier boiler; therefore, more heating surface, more grate area, and greater tractive weight are obtained. Grate areas of from 40 to 50 square feet are possible in this type which provides for the large fuel consumption that is required for the rather severe service. The heating surface is of equal importance since large cylinders require large steaming capacity. The 462 type meets this need also. A comparison of passenger locomotives shows that the Pacific type has more heating surface for a given total weight than is found in any other type of passenger locomotive.



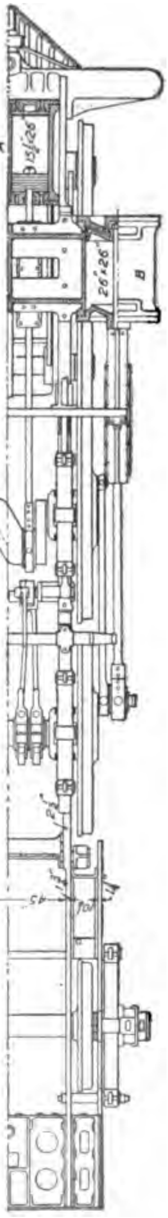


Fig. 14. Elevation of a Cole Four-Cylinder Balanced Compound Locomotive.
Fig. 15. Plan of the Same Locomotive.

Compound Locomotive. In continuation of a study of the development of the various types of locomotives, it is important to consider the compound locomotive. The compound locomotive is one in which the steam is admitted to one cylinder, called the *high-pressure cylinder,* where it partially expands. From this cylinder the steam is exhausted into the steam chest of another cylinder having larger dimensions, called the *low-pressure cylinder.* From this steam chest, the steam enters the low-pressure cylinder where it continues its work and is exhausted into the atmosphere. There have been a large number of different types of compound locomotives developed, all of which have had more or less merit. The following types have been used in America: the four-cylinder balance compound, the Mallet compound, and the tandem compound. The remarks and description which follow, of the *Cole four-cylinder compound,* are quoted from publications of the American Locomotive Company, builders of this locomotive:

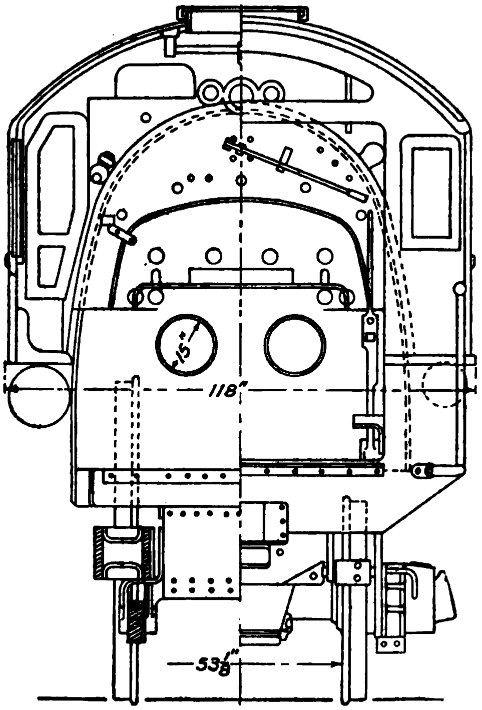
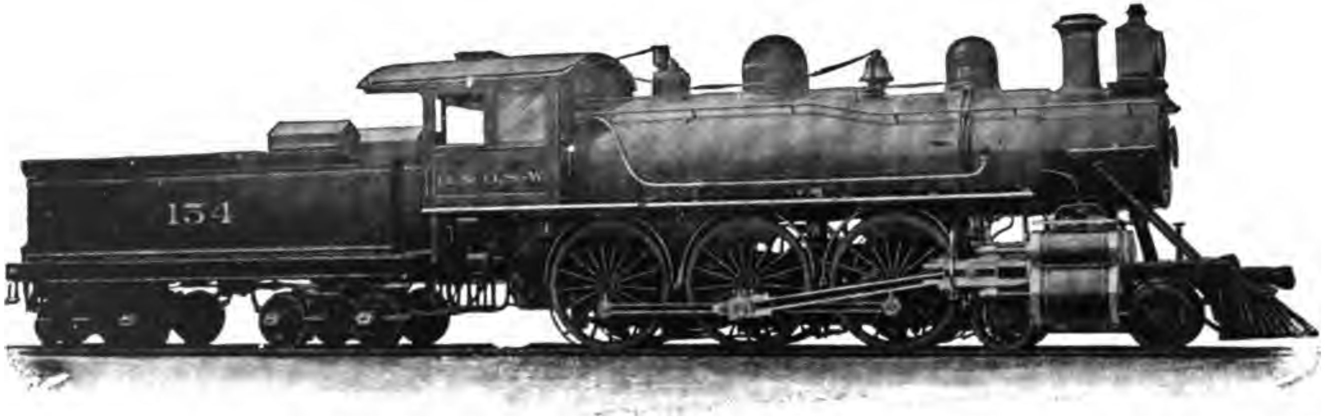


Fig. 16. Rear Elevation of the Cole Compound.

The time has arrived when merely increasing weight and size of locomotives to meet increasing weights of trains and severity of service does not suffice. To increase capacity, improve economy, and at the same time reduce injury to track, a new development is needed. Limits of size and weights have been reached in Europe and to meet analogous conditions there, the four-cylinder balanced compound has been developed into remarkably successful practice. The purpose of the Cole four-cylinder balanced compound is to advance American practice by adapting to our conditions the principles which



COMPOUND 10-WHEEL LOCOMOTIVE, BALDWIN LOCOMOTIVE WORKS—Total Weight of Engine, 76 Tons

have brought such advantageous results abroad, especially the principles of the de Glehn compound.

The Cole four-cylinder balanced compound employs the principle of subdivided power to the cylinders; the high pressure (between the frames) drives the forward or crank axle and the others; the low pressure (outside of the frames) drives the second driving axle. In order to secure a good length for connecting rods without lengthening the boiler, the high-pressure cylinders are located in advance of their usual position.

Special stress is laid on perfect balancing and the elimination of the usual unbalanced vertical component of the counterbalance stresses as a means for increasing the capacity, improving economy of operation and maintenance, and promoting good conditions of the track.

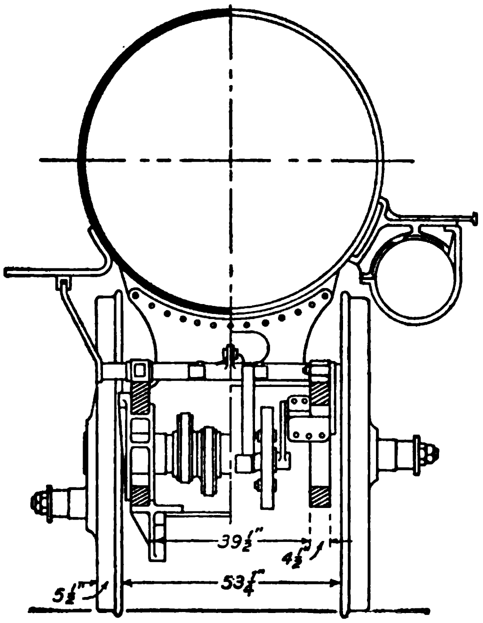


Fig. 17. Section of the Cole Compound.

The relative positions of the high-pressure cylinder *A* and the low-pressure cylinder *B* may be seen in Fig. 14 and Fig. 15. The high-pressure guides, Fig. 15, are located under and attach to the low-pressure saddle, whereas the low-pressure guides are in the usual location outside of the frames. The cranks of the driving wheels are 180 degrees apart. In order to equalize the weights of the pistons, those of the high-pressure cylinders are solid and those of the low-pressure cylinders are dished, and made as light as possible. A single valve motion, of the Stephenson type, operates a single valve stem on each side of the engine. Each valve stem carries two piston valves, one for the high- and the other for the low-pressure cylinder, as illustrated and explained later.

The back end, Fig. 16, and the two sections, Fig. 17 and Fig. 18, resemble ordinary construction of two-cylinder locomotives but the half front elevation and half section shown in Fig. 19 disclose a number of departures. The high-pressure piston rod, crosshead, and the guides *C* are shown in position under the low-pressure saddle. The high-pressure cylinders *A* and the high-pressure section of the piston valve chamber *D* are all in one casting, Fig. 20. The sides of the cylinder casting are faced off to the exact distance between the front plate extension of the frames. The valve chambers are in exact line with the valve chambers of the low-pressure cylinder; intermediate thimble

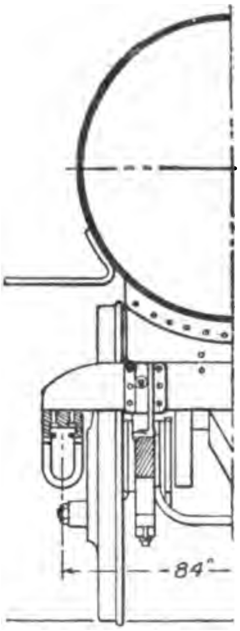


Fig. 18. Half-Section of the Cole Compound.

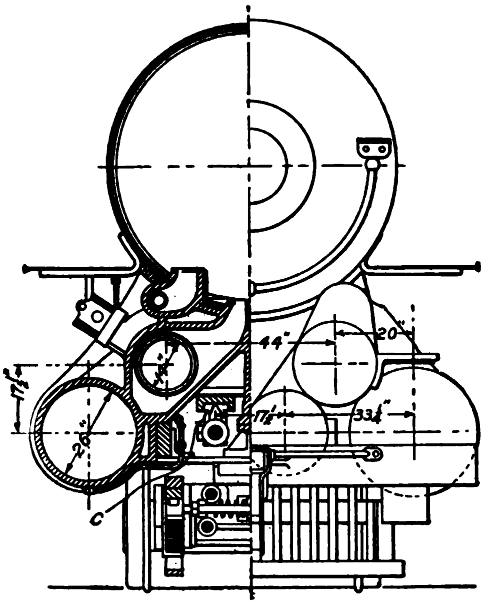


Fig. 19. Half Front Elevation and Half-Section.

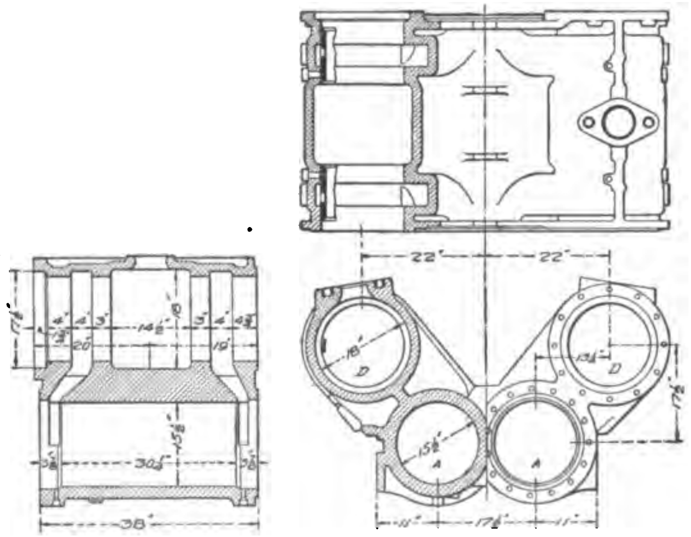


Fig. 20. Details of the Cylinders in the Cole Compound.

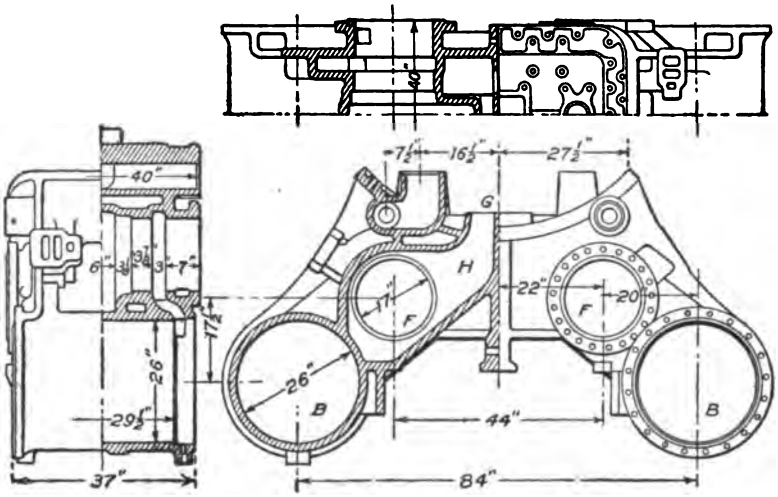


Fig. 21. Low-Pressure Cylinder Details.

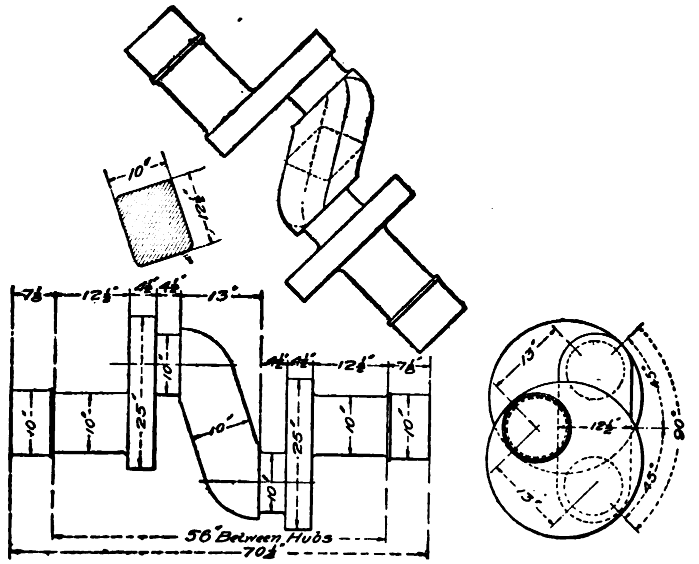


Fig. 22. The Crank Axle.

castings and packing glands being inserted between the two, form a continuous valve chamber common to both high- and low-pressure cylinders, thus providing for expansion.

Fig. 21 shows the low-pressure cylinders *B* which are cast separately and bolted together. In this case the inside of the cylinders are faced off to proper dimensions to embrace the outer faces of the bar frame. The low-pressure piston valve chamber *F* is in direct line between the cylinder and the exhaust base *G*. This view illustrates the short direct exhaust passage *H* from the low-pressure cylinders to the exhaust nozzle.

Fig. 22, the crank axle, shows that under the existing conditions it is possible to make this part exceedingly strong. Inasmuch as the cranks on this axle are 90 degrees from one another, it is possible to introduce exceedingly strong 10 by 12½ inch rectangular sections connecting the two crank pins. The whole forms an exceedingly strong and durable arrangement constructed in accordance with the best European practice which is likely both to wear and stand up well in service. A cross-section of the central portion of the axle indicates its proportions between the crank pins.

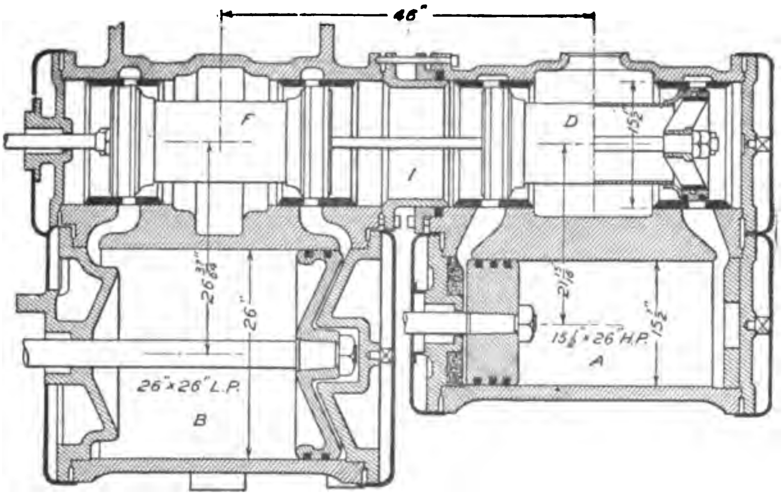


Fig. 23. Section of High- and Low-Pressure Cylinders Revolved into the Same Plane.

The high- and low-pressure cylinders, *A* and *B*, are shown in Fig. 23 as they would appear in section revolved into the same plane. The high-pressure valve *D* is arranged for central admission and the low-pressure valve *F* for central exhaust, both valves being hollow. A thimble casting or round joint ring and a gland connect the two parts of the continuous valve chamber *I*.

The following advantages of the four-cylinder balanced compound are claimed by the maker:

1. The approximately perfect balance of the reciprocating parts combined with the perfect balance of the revolving masses.

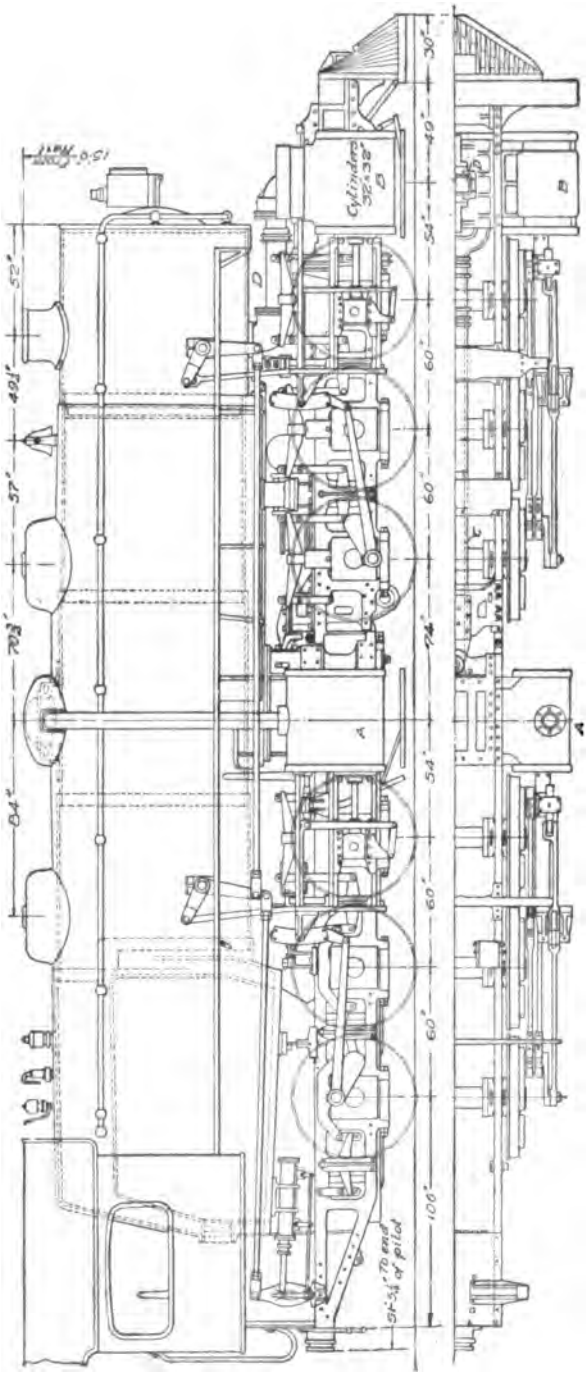


Fig. 24. Elevation of American Model of Mallet Articulated Compound.
Fig. 25. Half-Plan of the Same.

2. The permissible increase of weight on the driving wheels on account of the complete elimination of the hammer blow.

3. An increase in sustained horse-power at high speeds without modification of the boiler.

4. Economy of fuel and water.

5. The subdivision of power between the four cylinders and between the two axles, and the reduction of bending stress on the crank axle due to piston thrust because of this division of power.

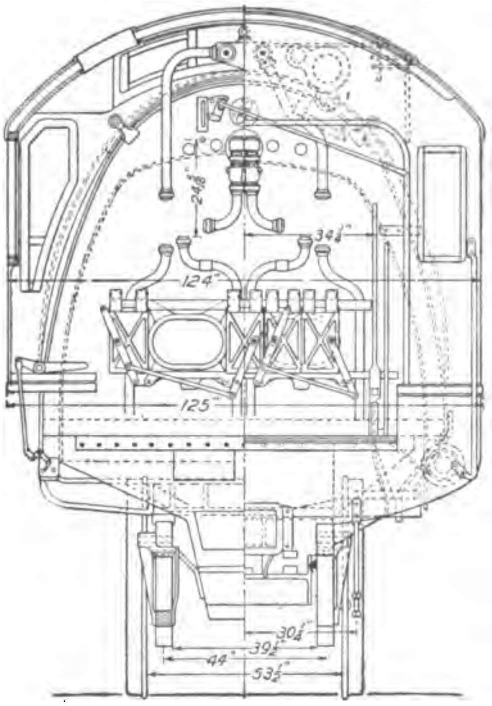


Fig. 26. Rear Elevation of the American Mallet.

6. The advantage of light moving parts which render them easily handled and which will minimize wear and repairs.

7. Simplicity of design One set of valve gears with comparatively few parts when compared with other designs which have duplicate sets of value gears for similar locomotives.

Another type of compound which is remarkable in many respects and which has had very successful usage in Europe is the *Mallet articulated compound.* It has been known and used in certain mountainous sections of Europe for several years but has recently been modified and adapted to meet American requirements. It is practically two separate locomotives combined in one, and advantage is taken of this opportunity to introduce the compound principles under the most favorable conditions. The following is a description together with dimensions of a large locomotive of this type built by the American Locomotive Company. Its enormous size is realized from Fig.

24 and Fig. 25. The weight of this particular locomotive in working order is nearly 335,000 pounds and the flues are 21 feet long. The rear three pairs of drivers are carried in frames rigidly attached to the boiler. To these frames, and to the boiler as well, are attached the high-pressure cylinders. The forward three pairs of drivers, however, are carried in frames which are not rigidly connected to the barrel of the boiler but which are in fact a truck. This truck swivels radially from a center pin located in advance of the high-pressure cylinder saddles. The weight of the forward end of the boiler is transmitted to the forward truck through the medium of side bearings, illustrated in Fig. 24, between the second and third pair of drivers. In order to secure the proper distribution of weight, the back ends of the front frames are connected by vertical bolts with the front ends of the rear frames. These bolts are so arranged that they have a universal motion, top and bottom, which permits of a certain amount of play between the front and rear frames when the locomotive is rounding a curve. The low-pressure cylinders are attached to the forward truck frames.

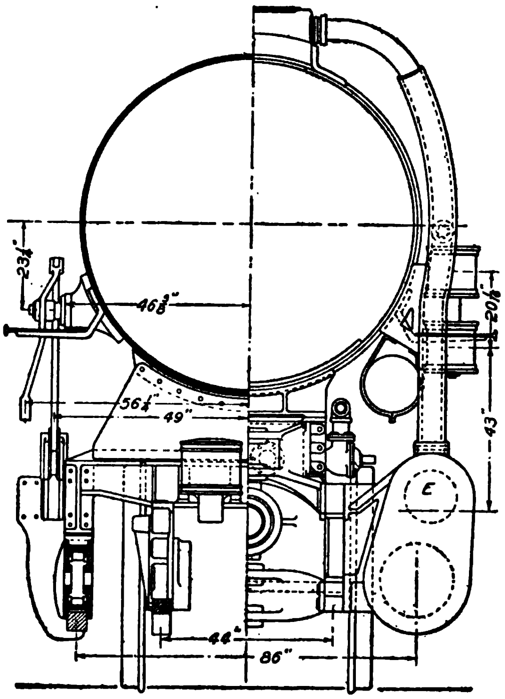


Fig. 27. Section of American Mallet Showing Method of Bringing Steam from Dome to High-Pressure Cylinder.

The steam dome is placed directly over the high-pressure cylinders *A* from which steam is conducted down the outside of the boiler on either side to the high-pressure valve chamber. The steam after being used in the high-pressure cylinders *A* passes to a jointed pipe

C between the frames and is delivered to the low-pressure cylinders *B*, whence it is exhausted by a jointed pipe *D* through the stack in the usual way. The back end, Fig. 26, presents no unusual feature other than the great size of the boiler and fire-box. The section shown in Fig. 27 illustrates the method of bringing the steam down from the steam dome to the high-pressure valve *E*. The section in Fig. 28 clearly shows the sliding support *F* between the boiler and front truck. It also shows the method of attaching the lift shafts to the boiler barrel which is made necessary by the use of the Walschaert valve gear. Fig. 29 shows that the low-pressure cylinders *B* are fitted with slide valves, and also shows the jointed exhaust pipe from the low-pressure cylinder to the bottom of the smoke-box. Fig. 30 illustrates the construction and arrangement of the flexible pipe connection *C* between the high-pressure cylinder *A* and the low-pressure cylinder *B*. This pipe connection, as well as the exhaust connection *D* between the low-pressure cylinder and the smoke stack, serves as a receiver. The ball joints are ground in, the construction being such that the gland may be tightened without gripping the ball joint.

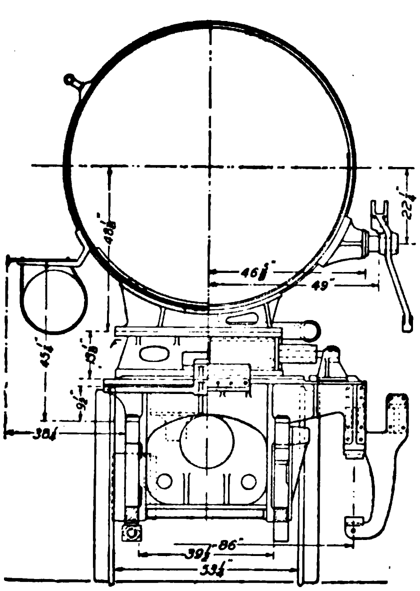
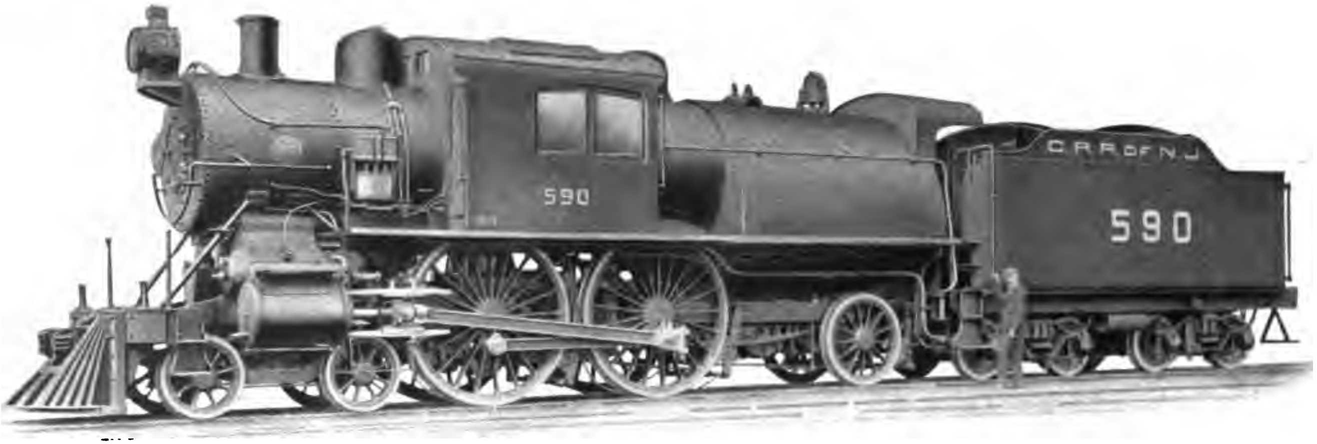


Fig. 28. Section of American Mallet.

The builders claim for this design about the same advantages over the simple engine as were enumerated in the description of the Cole four-cylinder balanced compound. It is evident that the Mallet compound is a large unit and hence can deliver more power with the same effort of the crew. A reserve power of about 20 per cent above the normal capacity of the locomotive may be obtained by turning live steam into all four cylinders and running the locomotive simple which can be done at the will of the engineer when circumstances demand it.



ATLANTIC TYPE, PASSENGER LOCOMOTIVE
American Locomotive Co.

The diagrammatic illustration shown in Fig. 31 presents a good means of studying and comparing the four different types of compound locomotives referred to in the preceding pages. Briefly stated, the essentials in each of the four cases illustrated are as follows:

Cole. High-pressure cylinders, inside but in advance of the smoke-box, driving front axle. Low-pressure cylinders, outside in line with the smoke-box, driving rear driving axle. Two piston valves on a single stem serve the steam distribution for each pair of cylinders, and each valve stem is worked from an ordinary link motion.

Vauclain. High-pressure cylinders inside and low-pressure cylinders outside, all on the same horizontal plane, in line with the smoke-box and all driving the front driving axle. As in the von Borries, a single piston valve worked from a single link effects the steam distribution for the pair of cylinders on each side

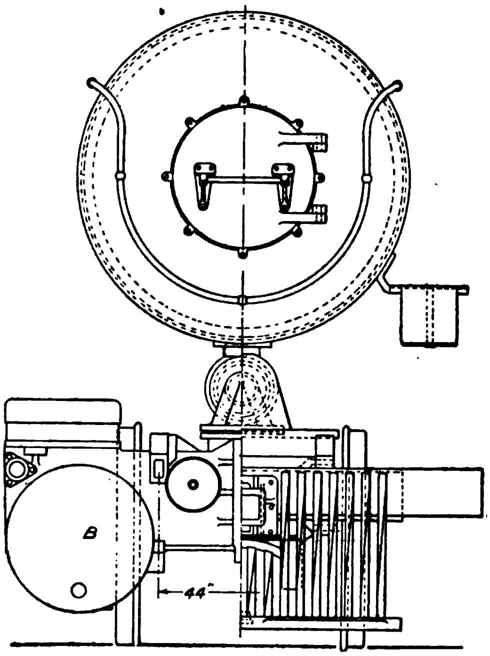


Fig. 29. **Forward Half-Section Showing Slide Valves in the Low-Pressure Cylinders.**

De Glehn. High-pressure cylinders, outside and behind smoke-box, driving the rear drivers. Low-pressure cylinders, inside under smoke-box, driving crank axle of front drivers. Four separate slide valves and four Walschaert valve gears allowing independent regulation of the high- and low-pressure valves.

Von Borries. High-pressure cylinders inside and low-pressure cylinders outside all on the same horizontal plane in line with the smoke-box and all driving the front driving axle. Each cylinder has its own valve but the two valves of each pair of cylinders are worked from a single valve motion of a modified Walschaert type. This

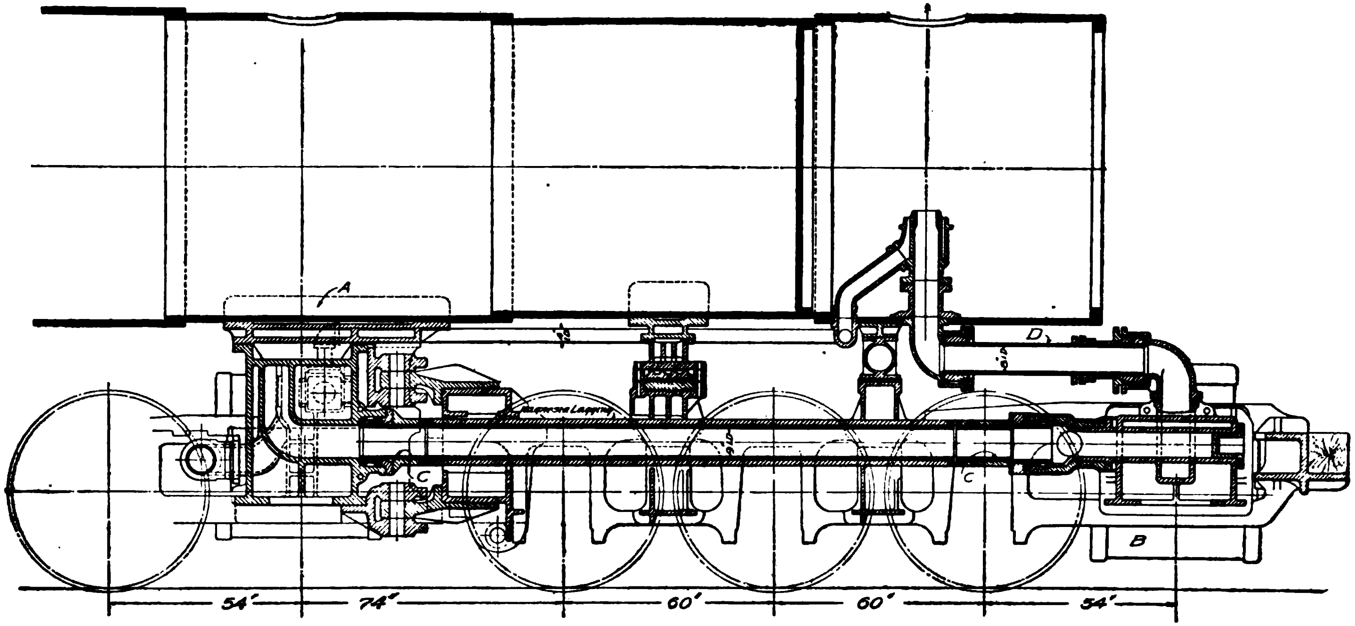


Fig. 30. Longitudinal Section of American Mallet Showing Flexible Pipe Connection Between High- and Low-Pressure Cylinders.

arrangement permits the varying of the cut-off of the two cylinders giving different ratios of expansion which cannot, however, be varied by the engine-man.

In addition to the compound locomotives already described, an early development of this type, known as the *Richmond*, or cross-compound, came into service. This engine differs from those already described in that it has only two cylinders, whereas those previously mentioned have four. In the cross-compound engine there is a high-pressure cylinder on the left side and a large or low-pressure cylinder on the right. The live steam passes from the boiler through the head and branch pipes to the high-pressure cylinder in the usual way. It is then exhausted into a receiver or circular pipe resembling the branch pipe which conveys the steam from the high-pressure cylinder across the inside of the smoke-box into the steam chest of the low-pressure cylinder. The steam passes from the steam chest into the cylinder and exhausts out through the stack in the usual way. The construction is such that the locomotive can be worked simple when starting trains. This type was never very largely used.

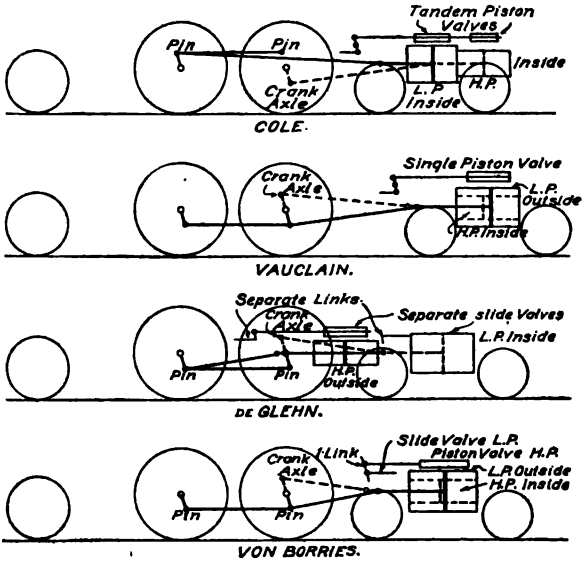


Fig. 31. Diagrams Showing Variations in the Four Principal Types of Compounds.

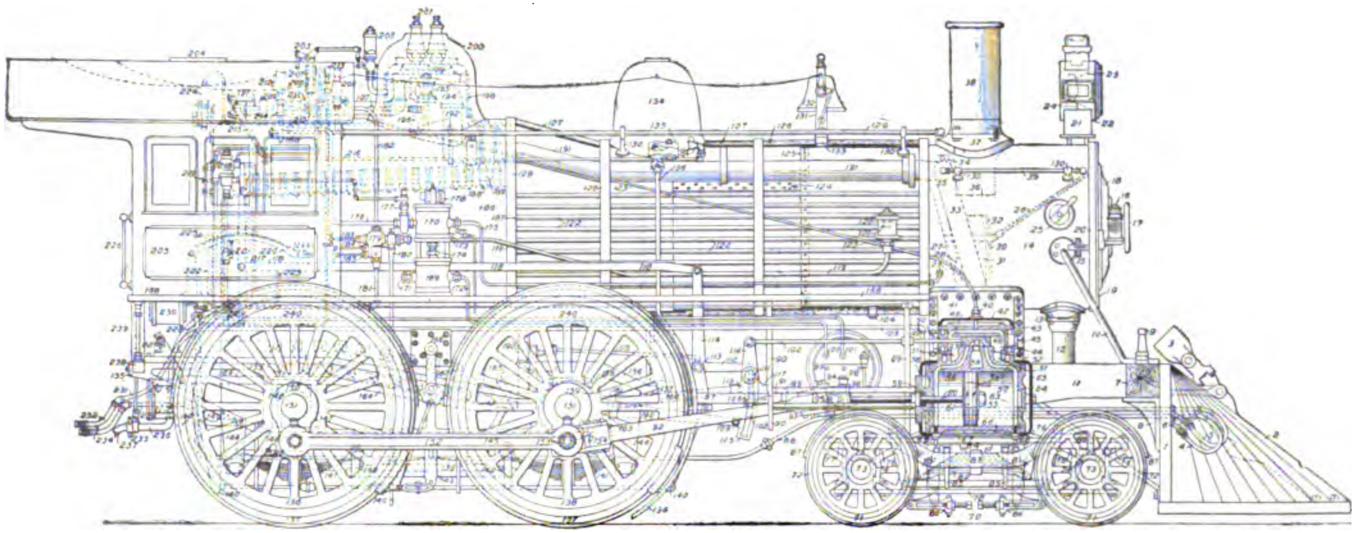


Fig. 32. Longitudinal Section of the American Locomotive.

1—Pilot. 2—Draw Head Attachment. 3—Folding Draw Head. 4—Air Signal Hose. 5—Air Brake Hose. 6—Hose Hangers. 7—Buffer Beam. 8—Pilot Bracket. 9—Flagstaff. 10—Arch Brace. 11—Front Frame. 12—Cinder Chute. 13—Cinder Chute Slide. 14—Extension Front. 15—Headlight Front. 16—Signal Lamp. 17—Number Plate. 18—Smoke Arch Door. 19—Smoke Arch Front. 20—Smoke Arch Ring. 21—Headlight Bracket. 22—Headlight Case. 23—Headlight Reflector. 24—Headlight Burner. 25—Cleaning Door. 26—Netting. 27—Deflector Plate. 28—Deflector Plate Adjuster. 29—Air Pump Exhaust Pipe. 30—Blower. 31—Nozzle Stand. 32—Nozzle Tip. 33—Steam Pipe (2). 34—T or Nigger Head. 35—Dry Pipe Joint. 36—Petticoat or Draft Pipe. 37—Stack Base. 38—Smoke Stack. 39—Arch Hand Rail. 40—Oil Pipe Plug. 41—Cylinder Saddle. 42—Steam Chest Casing Cover. 43—Steam Chest Cover. 44—Steam Chest. 45—Relief Valve. 46—Balance Plate. 47—Balanced Valve. 48—Valve Yoke. 49—Valve Stem. 50—Valve Stem Packing. 51—Steam Passages to Chest. 52—Valve Seat. 53—Bridges. 54—Exhaust Port. 55—Piston Rod Nut. 56—Steam Ports. 57—Cylinder. 58—Back Cylinder Head. 59—Piston Rod Packing. 60—Piston Rod. 61—Piston Head. 62—Piston Packing Rings. 63—Truck Center Castings. 64—Front Cylinder Head. 65—Cylinder Head Casing. 66—Cylinder Lagging. 67—Cylinder Casing. 68—Cylinder Cocks. 69—Cylinder Cock Rigging.

70—Engine Truck Wheel. 71—Engine Truck. 72—Engine Truck Tire. 73—Engine Truck Axle. 74—Engine Truck Brass. 75—Engine Truck Box. 76—Engine Truck Pedestal. 77—Engine Truck Frame. 78—Engine Truck Pedestal Brace. 79—Engine Truck Frame Brace. 80—Engine Truck Equalizer. 81—Engine Truck Spring Hanger. 82—Engine Truck Spring. 83—Engine Truck Spring Band. 84—Engine Truck Spring Pocket. 85—Safety Hanger. 86—Truck Brake. 87—Wheel Guard. 88—Signal Pipe. 89—Guides. 90—Guide Yoke. 91—Guide Block. 92—Main Rod. 93—Main Rod Front Strap. 94—Key. 95—Crosshead Pin. 96—Crosshead. 97—Main Frame. 98—Air Drum Bracket. 99—Air Drum. 100—Pump Connection. 101—Train Pipe Connection. 102—Valve Stem Rod. 103—Train Pipe. 104—Wash Out Plugs. 105—Link. 106—Suspension Stud. 107—Link Block Pin. 108—Link Block. 109—Eccentric Connection, Back Up. 110—Eccentric Connection, Go Ahead. 111—Link Hanger. 112—Tumbling Shaft Arm. 113—Tumbling Shaft. 114—Tumbling Shaft Lever. 115—Counterbalance Spring and Rig. 116—Rocker. 117—Rocker Box. 118—Reach Rod. 119—Branch Pipe. 120—Check Valve Case. 121—Check Valve. 122—Flues. 123—Oil Pipe. 124—Horizontal Boiler Seam. 125—Circumferential Seam. 126—Boiler Lagging. 127—Boiler Jacket. 128—Jacket Bands. 129—Hand Rail. 130—Hand Rail Brackets. 131—Bell Stand. 132—Bell. 133—Steam Bell Ringer. 134—Sand Box. 135—Pneumatic Sander. 136—Sand Pipe. 137—Driving Wheel Tire. 138—Driving Wheel Centers. 139—Ash Pan. 140—Driver Brakes. 141—Driver Springs. 142—Driver Spring Hangers. 143—Driver Spring Equalizers. 144—Driver Spring Hanger Brace. 145—Lower Rail of Frame. 146—Pedestal Brace. 147—Driving Box Shoe. 148—Driving Box Wedge. 149—Wedge Bolt. 150—Driving Box. 115—Driving Axle. 152—Side or Parallel Rod. 153—Rod Bush. 154—Main Rod Connection. 155—Main Frame. 156—Frame Brace. 157—Frame Splice. 158—Go Ahead Eccentric. 159—Back-Up Eccentric. 160—Go Ahead Eccentric Rod. 161—Go Ahead Eccentric Strap. 162—Back-Up Eccentric Rod. 163—Back-Up Eccentric Strap. 164—Grate Shaking Rig. 165—Rocking Grates. 166—Expansion Pad. 167—Expansion Link. 168—Running Board. 169—Air Cylinder Brake Pump. 170—Steam Cylinder Brake Pump. 171—Air Strainer. 172—Delivery to Drum. 173—Drip Cock. 174—Pump Piston Packing. 175—Pump Exhaust Connection. 176—Pump Steam Connection. 177.—Governor. 178—Pump Valve Case. 179—Injector. 180—Injector Overflow. 181—Water Pipe. 182—Steam Pipe. 183—Steam Valve. 184—Primer. 185—Water Valve. 186—Fire Box. 187—Tube Sheet. 188—Crown Bars. 189—Sling Stays. 190—Stay Bolts. 191—Dry Pipe. 192—Stand Pipe. 193—Dry Pipe Hangers. 194—Throttle Pipe. 195—Throttle Valve. 196—Throttle Bell Crank. 197—Throttle Stem. 198—Dome. 199—Dome Cap. 200—Dome Casing. 201—Safety Valves. 202—Chime Whistles. 203—Whistle Rig. 204—Ventilator. 205—Cab. 206—Air Pump Lubricator. 207—Air Gauge. 208—Steam Gauge. 209—Steam Turret. 210—Injector Throttle. 211—Blower Cock. 212—Gauge Lamp. 213—Signal Whistle. 214—Air Pump Throttle. 215—Throttle Lever. 216—Pneumatic Sander. 216*a*—Sand Lever. 217—Reverse Lever. 218—Engineer's Brake Valve. 219—Gauge Cocks. 220—Quadrant. 221—Cut Out Valve. 222—Fire Door. 223—Cylinder Cock Lever. 224—Cylinder Lubricator. 225—Oil Can Shelf. 226—Hand Hold. 227—Shake Lever Stub. 228—Ash Pan Damper Handle. 229—Whistle Signal Valve. 230—Brake Valve Reservoir. 231—Train Pipe. 232—Train Pipe Hose. 233—Signal Pipe. 234—Signal Pipe Hose. 235—Feed Pipe Hanger. 236—Feed Pipe. 237—Feed Pipe Hose. 238—Tail Piece of Frame. 239—Cab Bracket. 240—Counterbalance Weight.

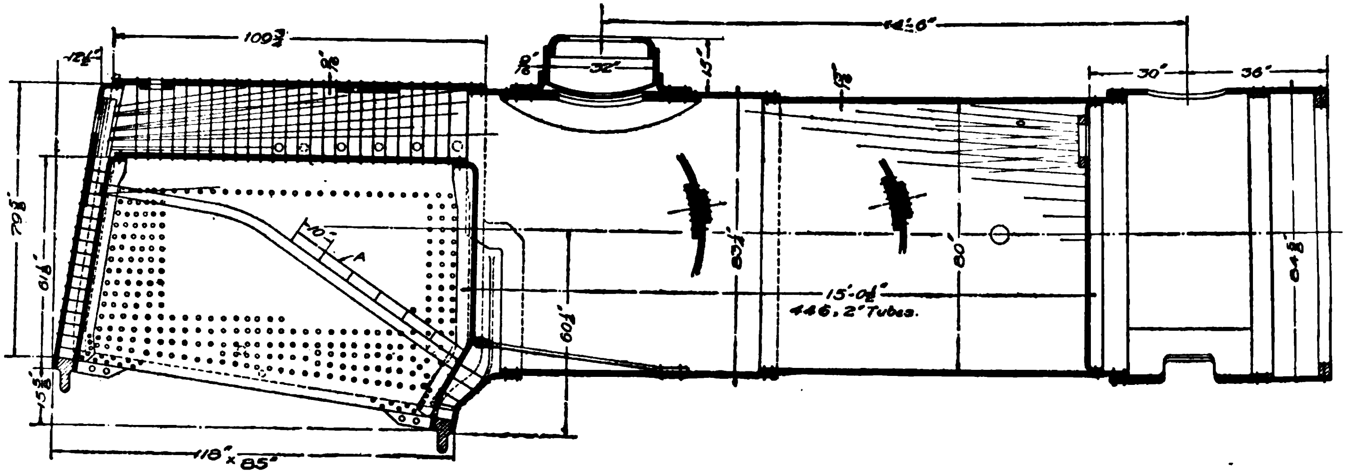


Fig. 33. Straight Top Form of Locomotive Boiler.

LOCOMOTIVE BOILERS

Before entering into the details of the various elements comprising a locomotive, it is thought advisable to give them some study in order to become familiar with the names of the various parts and their relation to each other. Fig. 32 is given for this purpose and represents a longitudinal section of a 440 type locomotive with all parts numbered and named. This figure should be carefully studied in order that the future work of the text may be clearly understood.

A *locomotive boiler* may be defined as a steel shell containing water which is converted into steam, by the heat of the fire in the fire-box, to furnish energy to move the locomotive.

Locomotive boilers are of the internal fire-box, straight fire-tube type having a cylindrical shell containing the flues and an enlarged back-end for the fire-box, and an extension front-end or smoke-box leading out from which is the stack.

Classification of Boilers as to Form. Locomotive boilers are classified as to form as follows:

Straight top, Fig. 33, which has a cylindrical shell of uniform diameter from the fire-box to the smoke-box.

Wagon top, Fig. 34, which has a conical or sloping course of plates next to the fire-box and tapering down to the circular courses.

Extended wagon top, Fig. 35, which has one or more circular courses between the fire-box and the sloping courses which taper to the diameter of the main shell.

Classification of Boilers as to Fire-Box Used. Boilers are frequently referred to also and designated by the type of fire-box contained, such as *Belpaire*, *Wooten*, and *Vanderbilt*. This designation does not in any way conflict with the classification of different types of boilers already given but refers to the general character of the fire-box; that is, the boiler may be classified as a straight top boiler and at the same time a Wooten fire-box. Since this is true it is necessary to know the distinction between the Belpaire, the Wooten, and the Vanderbilt types of fire-box.

The *Belpaire boiler*, as illustrated in Fig. 36, has a fire-box with a flat crown sheet *A* jointed to the side sheets *B* by a curve of short radius. The outside sheet *C* and the upper part of the outside sheets *D* are flat and parallel to those of the fire-box. These flat parallel

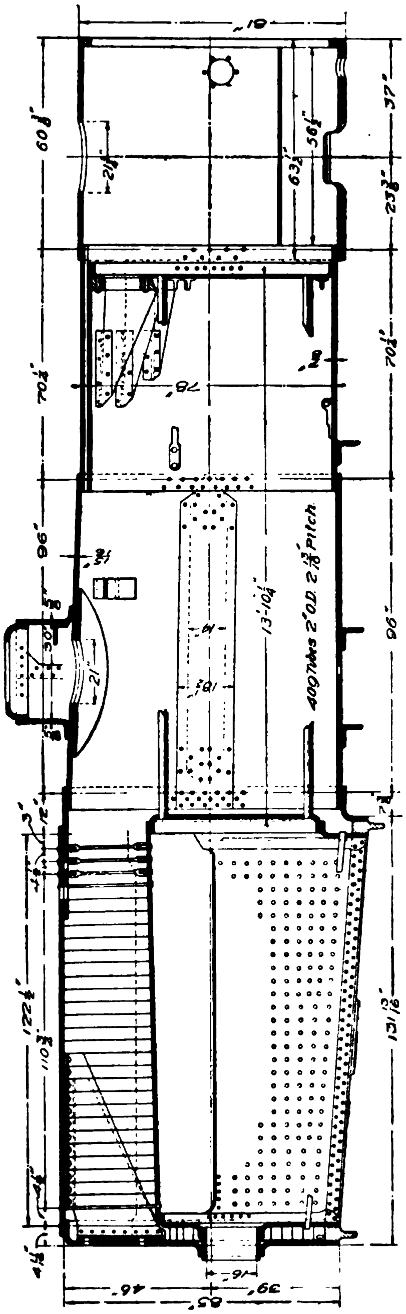


Fig. 34. Wagon Top Form of Locomotive Boiler.

plates are stayed by vertical and transverse stays and obviate the necessity of crown bars to support and strengthen the crown sheet. The advantage gained is that the stay bolts holding the crown and side sheets can be placed at right angles to the sheets into which they are screwed.

The *Vanderbilt fire-box* is built of corrugated forms, as illustrated in Fig. 37. The principal object in the design of this fire-box is to eliminate stay bolts which are a source of much trouble and expense in keeping up repairs. Only a few locomotives fitted with this type of fire-box have been used.

The *Wooten fire-box,* so-called, obtained its name from the designer. This form of fire-box extends out over the frames and driving wheels, as may be seen from Fig. 38. It was designed for the purpose of burning fine anthracite coal but soon after its introduction it found favor with a few railroads using bituminous coal. The drawing shown in Fig. 39 illustrates its general construction. It has rendered good service in certain localities but has never been very extensively used.

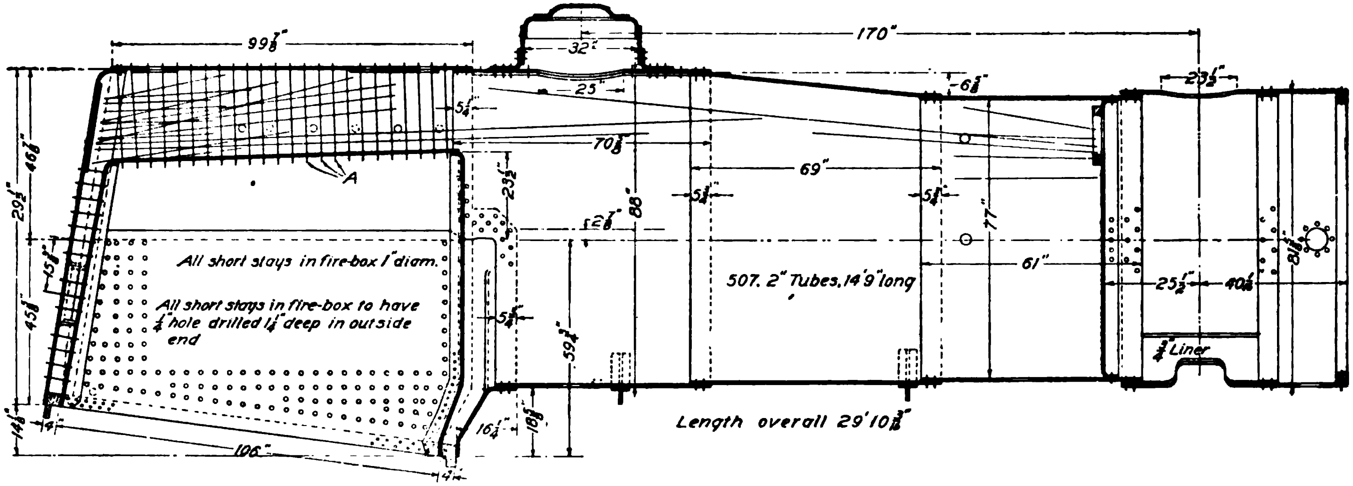


Fig. 35. Extended Wagon Top Form of Locomotive Boiler.

In addition to the designations given the various boilers already mentioned, they are frequently spoken of as narrow or wide fire-box locomotives. A *narrow fire-box* is one which is placed between the frames or may rest on the frames between the driving wheels. These conditions limited the width of the fire-box from 34 to 42 inches. *Wide fire-boxes* are those which extend out over the wheels, as is the case in the Wooten, their width only being limited by road clearances. The dimensions commonly used are as follows: width 66, 76, 85, 103, and 109 inches; length 85, 97, 103, 115, and 121 inches, all dimensions being taken inside of the fire-box ring. Variations above and below these figures are often found which are made necessary by existing conditions.

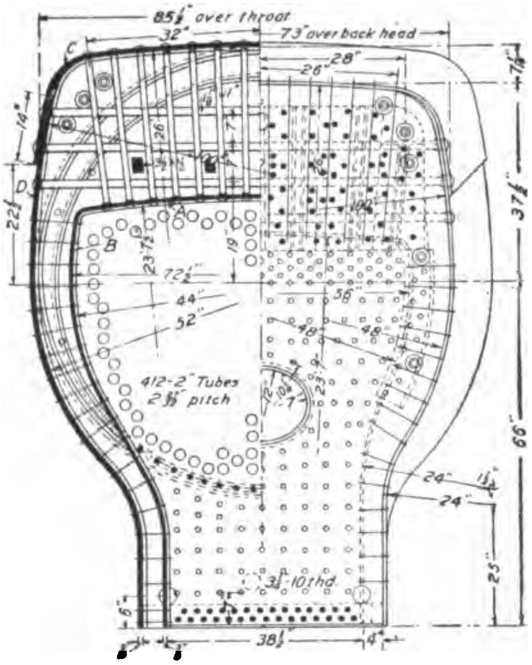


Fig. 36. Belpaire Boiler.

In locomotives where the fire-box is placed between the axles, the length of the fire-box is limited by the distance between the axles and is rarely more than 6 or 9 feet, from which the front and back legs must be deducted. Placing the fire-box on top of the frames

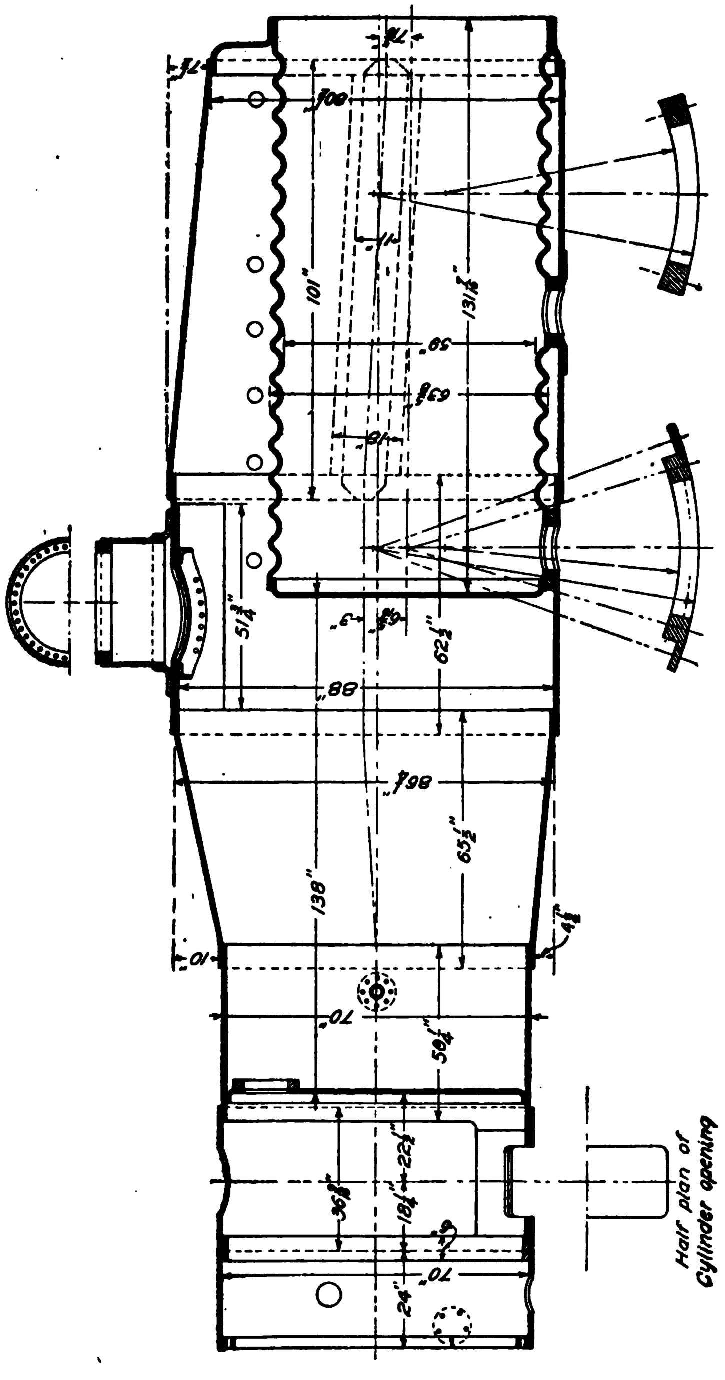


Fig. 37. Vanderbilt Fire-Box.

makes any length possible, the length being governed by the capability of the fireman to throw the coal to the front end of the fire-box.

Flues. From the sectional view of the boiler illustrated in Fig. 32 and Fig. 44, it is evident that a large part of the boiler is composed of flues or tubes. The flues give to the boiler the largest part of its heating surface. It is the flues which largely affect the life of the boiler and, therefore, the life of the locomotive, for this reason it is quite necessary to properly install and maintain them. A large amount of the repair costs is directly traceable to the flues. This is especially true in localities where water is found which causes scale to form on the flues from $\frac{1}{16}$ to $\frac{1}{2}$ inch in thickness, thus causing unequal expansion and contraction and overheating. These conditions cause the joints to break at the flue sheets. Cold air entering the fire-box door is another source of flue trouble. It is to these details that careful attention must be given in order to alleviate flue failures. Flues should be made of the best quality of charcoal iron, lap-welded, and subjected to severe tests before being used. They must be accurately made, perfectly round and smooth, must fill standard gauges perfectly, must be free from defects such as cracks, blisters, pits, welds, etc., and must be uniform in thickness throughout except at the weld where $\frac{8}{100}$ of an inch additional thickness may be allowed. The present practice is to use tubes of from 2 to $2\frac{1}{4}$ inches in diameter. They vary in length from about 15 to 20 feet, the length depending on the construction of the boiler and locomotive as a whole. The tubes

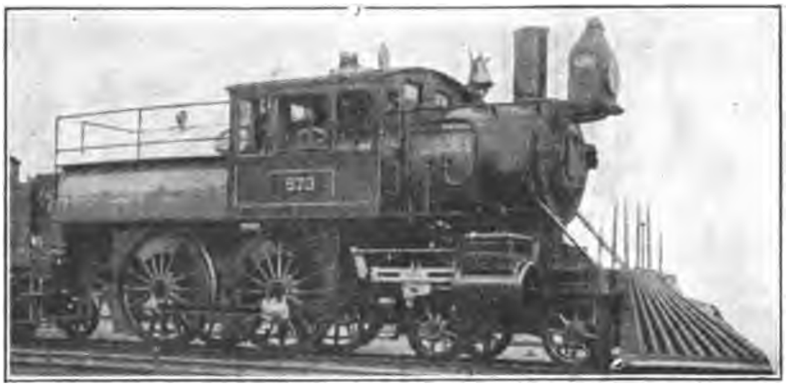


Fig. 38. Engine with Wooten Fire-Box.

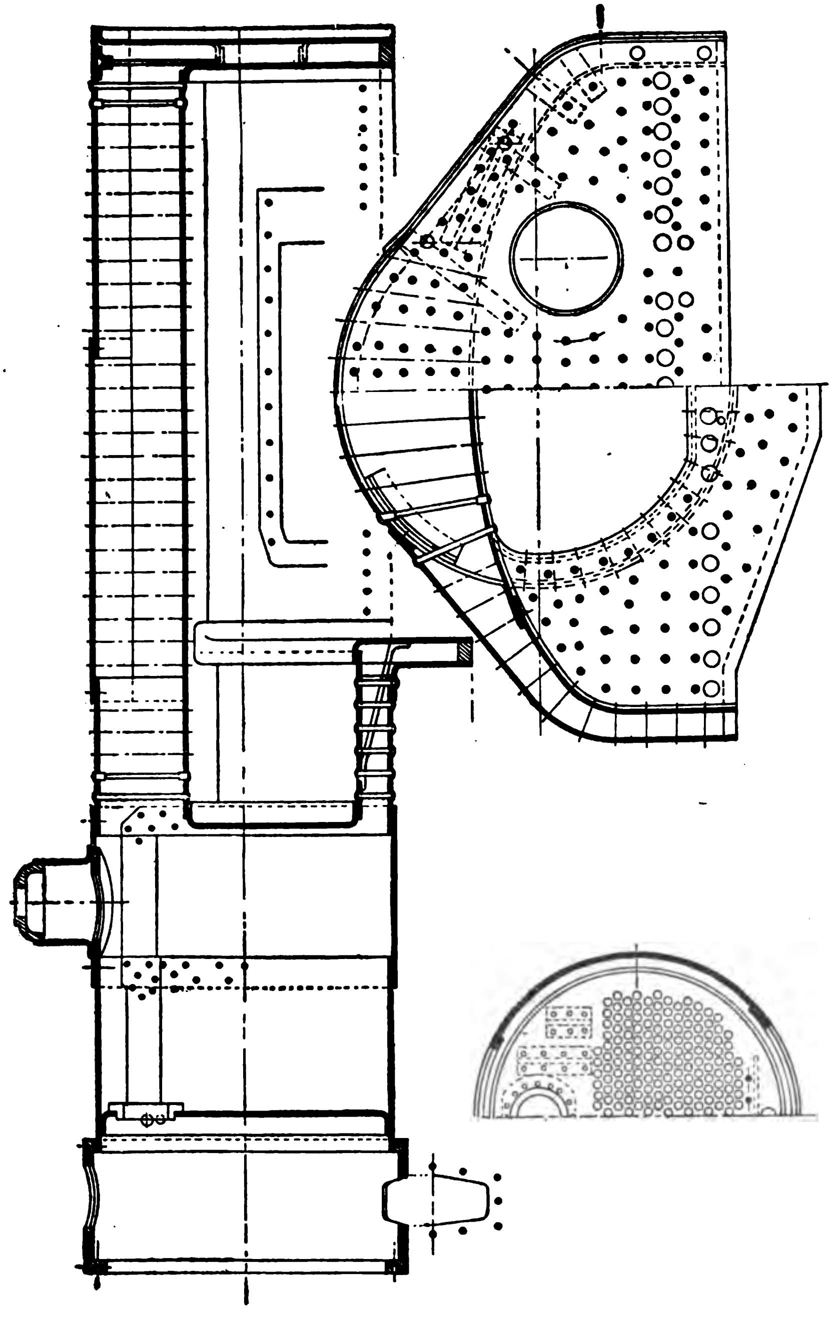


Fig. 39. Details of Wooten Fire-Box.

are supported at each end by letting them extend through the tube sheets. It is in the setting of the tubes that great care should be exercised. The tube sheets must be carefully aligned and the hole drilled through and reamed. These holes are usually made $\frac{1}{16}$ of an inch larger in diameter than the outside diameter of the tubes. The tubes should be made not less than $\frac{1}{4}$ nor more than $\frac{3}{8}$ inch longer than the gauge distance over the front and back flue sheets. All back ends of tubes should be turned and beaded, and at least ten per cent of those in the front end. The number of tubes used varies according to the type and size of the locomotive but usually from 300 to 500 are employed. The flue sheets are made thicker than the other sheets of the boiler in order to give as wide a bearing surface for the tubes as possible. They are usually $\frac{5}{8}$ inch thick. The flue sheets are braced or stayed by the flues and by diagonal braces fastened to the cylindrical shell. The bridges or metal in the flue sheets between two adjacent flues are usually made from $\frac{3}{4}$ to 1 inch in width. The greater the width of the bridges, the greater the space between the flues; therefore, better circulation will be obtained.

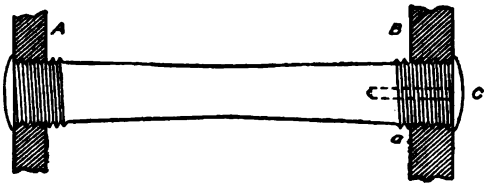


Fig. 40. Screw Stay-Bolt.

Stay-Bolts. The universal method of staying flat surfaces of the fire-box at the sides and front is by the use of stay-bolts. These stay-bolts are screwed through the two sheets of the fire-box and are riveted over on both ends. Fig. 40 illustrates a stay-bolt screwed into position and represents a strong and serviceable form. The stay-bolt is cut away between the sheets and only sufficient thread is cut at the ends to give it a hold in the metal. In Fig. 40, *A* represents the inside sheet or the one next to the fire, and *B* represents the outside sheet. A small hole *C* is drilled into the outside end of the stay-bolt. This is known as the *tell-tale hole* and will permit the escape of water and steam should the bolt become broken. This tell-tale hole is usually $\frac{3}{16}$ of an inch in diameter and $1\frac{1}{4}$ inches deep and is drilled at the outer end of the stay-bolt, since almost invariably the fracture occurs near the outer sheet. All boiler stay-bolts, including radial stays, have 12 Whitworth standard threads per inch. The most common cause of stay-bolts breaking is the bending at the point *B*, Fig. 40, due to the expansion of the sheets *A* and *B*. The sheet *A*, being next to the fire, is kept at a much higher temperature while the boiler is at work than the sheet *B*, which is subjected to the comparatively cool temperature of the atmosphere. This causes the plates *A* and *B* to have a movement relative to each other due to unequal expansion. The breakage is greatest at points where the greatest amount of movement takes place. As the two sheets are rigidly fastened to the mud ring, it is evident that the variation of expansion must start from that point; hence, the greatest vertical variation will be found at the top of the fire-box. In like manner, the back heads are securely fastened by stay-bolts so that horizontal variation must start at the back end; consequently the greatest horizontal variation will be found at the front end of the fire-box. The result of these two expansions will, therefore, be greatest at the upper portion of the front end. It is there that the greatest number of staybolt breakages occur.

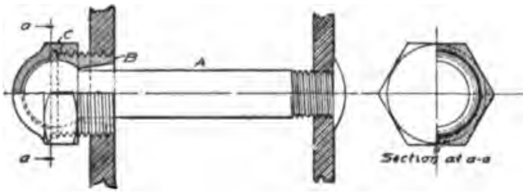


Fig. 41. Flexible Stay-Bolt.

In order to avoid these bending stresses, a number of different forms of flexible stay-bolts have been designed. One form of these is shown in Fig. 41. The stay-bolt proper, *A*, has a ball formed on one end and a thread cut on the other. A plug *B* sets over the ball and forms a socket in which the latter can turn. As the stay-bolt is free to revolve in the plug, there is no necessity of the thread of the stay-bolt being cut in unison with the thread on the plug. Such a stay-bolt as this permits the inner sheet of the fire-box to move to and fro relative to the outer sheet without bending the outer end of the stay-bolt. Flexible stay-bolts when used are placed in what is known as the *zone of fracture*. Fig. 42 and Fig. 43 illustrate the application of flexible stay-bolts to a wide fire-box. Fig. 42 shows five rows of flexible stay-bolts at each end of the fire-box and four rows at the bottom parallel to the mud ring. It should be remembered, however, that this is one installation only and that the arrangement in all cases may vary but this illustration is representative of good practice. Another illustration is shown in Fig. 45. Here the flexible stay-bolts are shown by shaded circles. It is evident from Fig. 43 that all the stays in the throat sheet are flexible, which is a very good arrangement since the stay-bolts in the throat sheet are subjected to very severe strains. On some railroads, flexible stay-

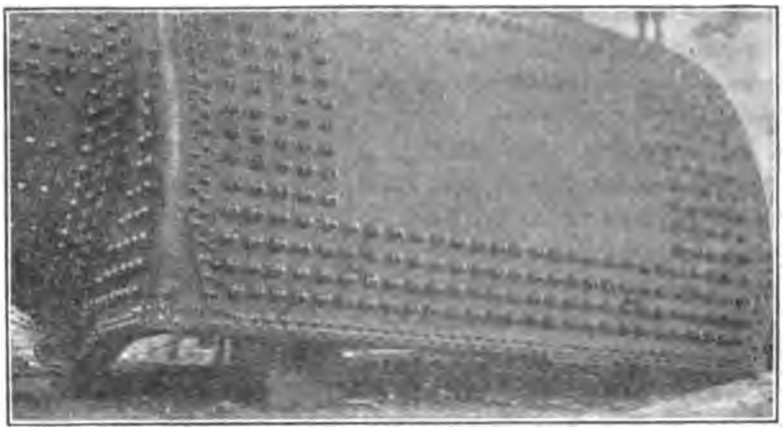


Fig. 42. Boiler, Showing Use of Flexible Stay-Bolts.

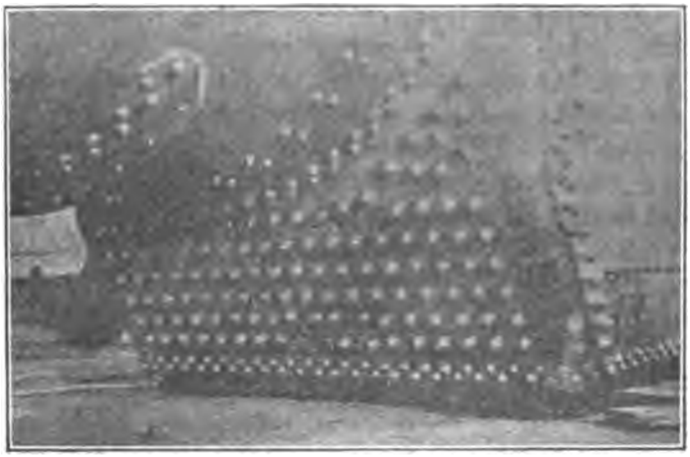


Fig. 43. Boiler, Showing Use of Flexible Stay-Bolts.

bolts are put in the fire-box door sheets but this practice varies in some details for different roads.

Stay-bolts should be made of the best quality double refined iron free from steel, having a tensile strength of not less than 48,000 pounds per square inch. The bars must be straight, smooth, free from cinder pits, blisters, seams, or other imperfections. The common practice is to use stay-bolts $\frac{7}{8}$ or 1 inch in diameter spaced about 4 inches from center to center.

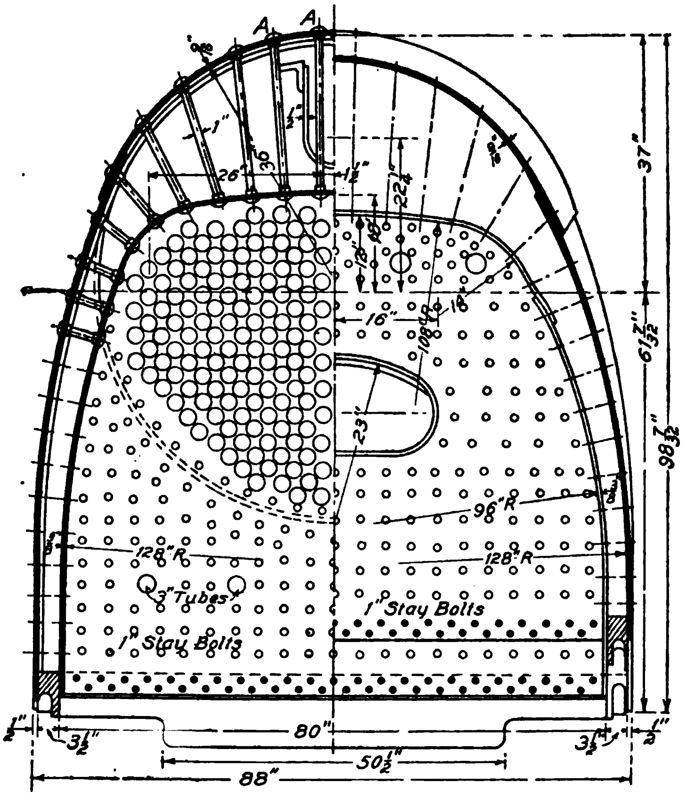


Fig. 44. Section of Boiler Having Radial Stays.

Stay-bolt breakage is very large in bad water districts and gives a great deal of trouble on most railroads. The stay-bolt problem, therefore, is a very important one.

In addition to staying the sides and front and back ends, it is also necessary to stay the crown sheet. To accomplish this, two general methods have been used. The oldest of these, by the use of crown bars, has almost passed out of service and well it is because of the many objectionable features it possessed. In this method, a number of crown bars were used which were supported by the edges of the side sheets and which were held apart by spacers resting upon the crown sheet and to which the crown bars were tied by bolts. The crown sheet was supported by stay-bolts which were bolted to the crown bars. A great deal of the space over the crown sheet was taken up by these crown bars which greatly interferred with the circulation and made it very difficult in cleaning. The second method of staying the crown sheet is by means of radial stays. All stay-bolts over 8 inches in length are usually classified as radial stays. Radial stay-bolts are of the same general type and material as the stay-bolts already described, and are put in on radial lines; hence their name. Fig. 44 shows a section of a boiler having radial stays *A*. These stays extend around the curved surface of the fire-box from the back to within two or three rows of the front end as illustrated at *A*, Fig. 45. The stays *B* in Fig. 45 are of a different form and are frequently used in the front end to allow for expansion and contraction of the flue sheet. These extend around to the curved surface in the same manner as do the radial stays shown in Fig. 44.

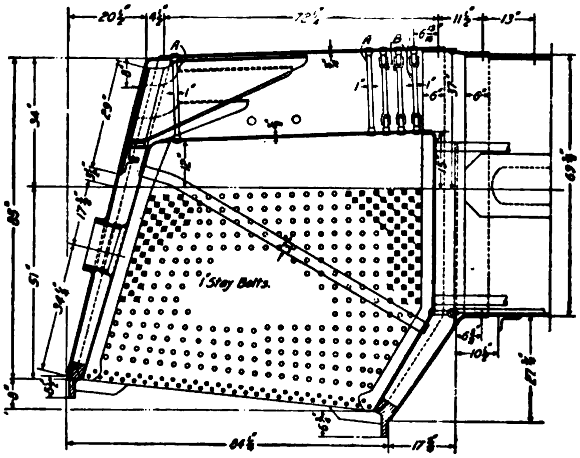


Fig. 45. Section Showing Two Types of Stays.

All radial stays should have enlarged ends with bodies $\frac{3}{16}$ inch smaller in diameter than the outside diameter of thread. They should be made with button heads and should have threads under heads increased in diameter by giving the end a taper $\frac{1}{2}$ inch in 12 inches. Radial stays commonly used are 1 inch, $1\frac{1}{8}$ inch, and $1\frac{1}{4}$ inch in diameter at the ends. The allowable safe fiber stress is 4,500 pounds per square inch.

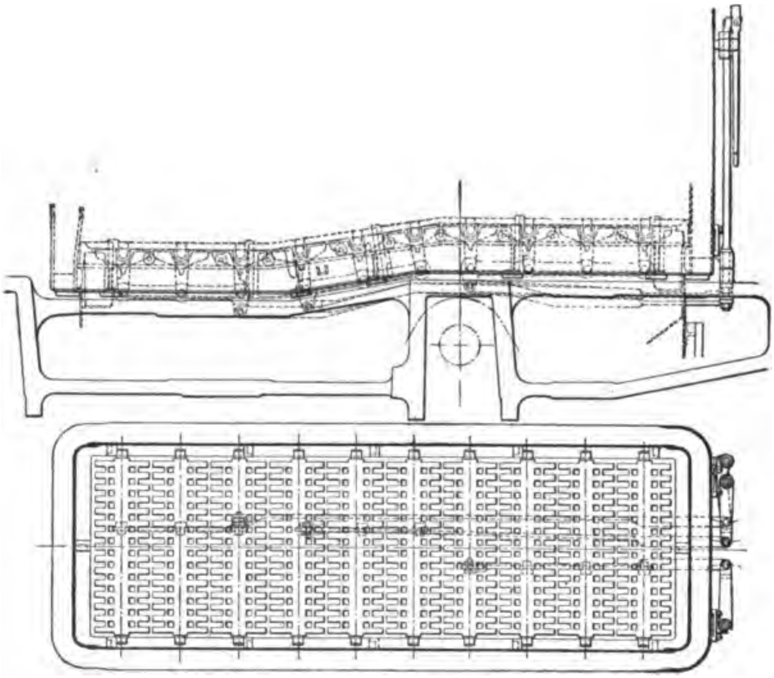


Fig. 46. Elevation and Plan of Grate.

Grates. The grate is made up of a set of parallel bars at the bottom of the fire-box, which hold the fuel. These bars are commonly made of cast iron and constructed in sections of three or four bars each. They are supported at their ends by resting upon a frame and are connected by rods to a lever which can be moved back and forth to rack the bars and shake ashes and cinders out of the fire. A drawing of such a grate is illustrated in Fig. 46. When the grates occupy the full length of the fire-box they are divided into three sections, any one of which can be moved by itself.

In the burning of anthracite coal, *water grates* are commonly used, a type of which is illustrated in Fig. 47 and Fig. 48. In Fig. 47, the grate is formed of a cube *a* expanded into the back sheets of the fire-box and inclined downward to the front in order to insure a circulation of water. Opposite the back opening, a plug is screwed into the outer sheet which affords a means whereby the tube may be cleaned and a new one inserted in position if a repair is needed. At the front end, the tube is usually screwed into the flue sheet. Water grates are rarely used alone but usually have spaced between them plain bars. These bars pass through tubes expanded into the sheets of the back water leg and by turning them, the fire may be shaken; and by withdrawing them, it may be dumped. Fig. 48 shows a cross-section of the arrangement usually employed. In this figure, *A* represents the water tube and *B*, the grate bars.

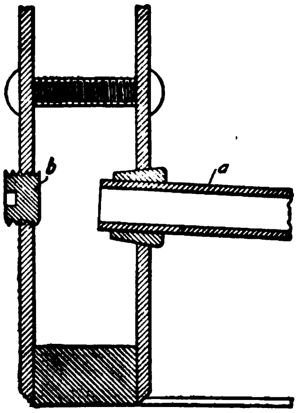


Fig. 47. Details of Water Grate for Anthracite Coal.

Ash Pans. Ash pans are suspended beneath the fire-box for the purpose of catching and carrying the ashes and coal that may drop between the grate bars. They are made of sheet steel. Fig. 49 illustrates a longitudinal section of an ash pan commonly used in fire-boxes placed between the axles of the engine. It is provided at each end with a damper *a* hinged at the top and which may be opened and set in any desired position in order to regulate the flow of air to the fire. It is quite important that the dampers should be in good condition in order that the admission of air to the fire may be

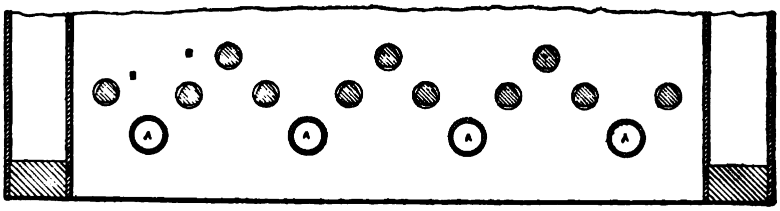
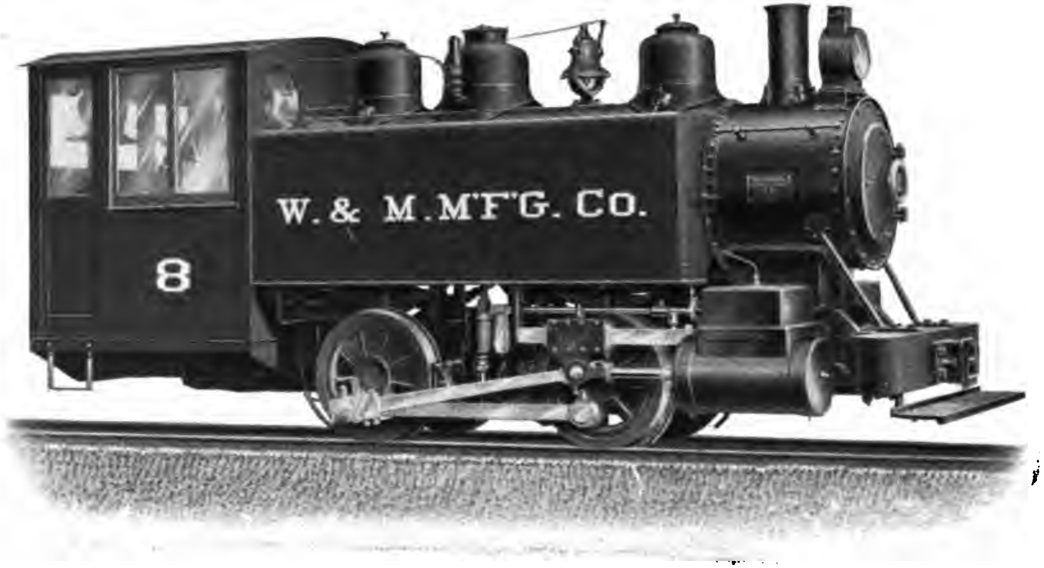


Fig. 48. Cross-Section of Water Grate.



FOUR-WHEEL SIDE TANK LOCOMOTIVE, 0-4-0 TYPE
For Industrial Service
American Locomotive Co.

regulated. The total unobstructed air openings in the ash pan need not exceed the total tube area but should not be less than 75 per cent. For many years the type shown in Fig. 49 was almost universally used. More recently, however, a damper capable of better adjustment and more easily kept in condition has been developed. Such a damper is illustrated in Fig. 50. In this type the dampers are placed upon the front faces of the ash pan and are raised and lowered by the contraction of levers and bell cranks. For example, the lifting of the bar *a* turns the bell crank *d* which pulls the connection *c c* which operates the forward bell crank and opens the front damper. In a similar manner, the rear damper *i* may be operated. If these dampers were made of cast iron and work in guides, it is possible to

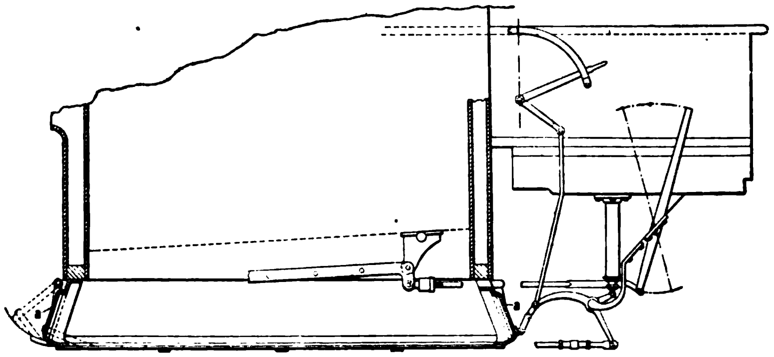


Fig. 49. Ash Pans Showing Old Lower Damper.

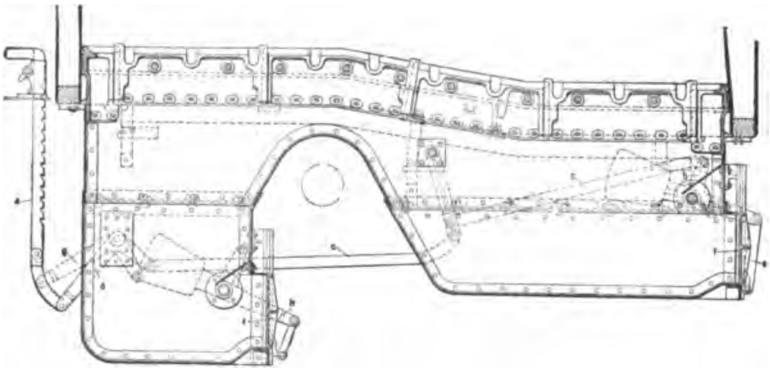


Fig. 50. New Form of Damper.

have the construction such that when closed they will be practically air tight.

Brick Arches. A brick arch is an arrangement placed in the fire-box to effect a better combustion and to secure a more even distribution of the hot gases in their passage through the tubes. Fig. 33 illustrates a longitudinal section of the fire-box fitted with a brick arch *A*. Its method of action is very simple. It acts as a mixer of the products of combustion with the air and as a reflector of the radiant heat of the fire and the escaping gases. It is maintained at a very high temperature and in this condition meets the air and gases as they come in contact with it and turns them back to the narrow opening above. By this action it maintains a temperature sufficiently high to burn with the smallest possible quantity of air all the carbonic oxide and the hydrocarbons that arise from the coal. It thus effects a very considerable saving in the cost of running, does away to a great extent with the production of smoke, and develops a high calorific power in comparatively small fire-boxes. This is a valuable property since it is possible for the boiler to utilize the heat value of the coal to the greatest possible extent. The bricks are usually about 4 or 5 inches thick and are ordinarily supported either by water tubes, as shown in Fig. 33 and Fig. 45, or by brackets in the form of angle-irons riveted to the side sheets. The disadvantage accruing from the use of the brick arch is that it is somewhat expensive to maintain because of the rapid deterioration and burning away of the material.

Smoke-Box and Front End Arrangement. By the term *front end* is meant all that portion of the boiler beyond the front tube sheet and includes the cylindrical shell of the boiler and all the parts contained therein such as the steam or branch pipes, exhaust nozzle, netting, diaphragm, and draft or petticoat pipes. These parts referred to above are illustrated in the sectional view shown in Fig. 32.

The Steam or Branch Pipes. These pipes, 33, follow closely the contour of the shell and connect the T-head, 34, with the steam passage leading to the cylinder and conduct the steam from the dry-pipe to both the right and the left cylinders.

Exhaust Nozzle. The exhaust nozzle is the passage through which the steam escapes from the cylinders to the stack.

Netting. The netting, 26, is a coarse wire gauze placed in the front end which prevents large cinders from being thrown out by the action of the exhaust and thereby reduces the chances for fires being started along the right of way.

Diaphragm. The diaphragm or deflector plate, 27, is an iron plate placed obliquely over a portion of the front end of the flues which deflects the flue gases downward before entering the stack, thus equalizing to a great extent the draft in the different flues. This deflector plate may be adjusted to deflect the gases more or less as desired.

Draft Pipes. The petticoat or draft pipes, 36, employed to increase the draft may be used singly or in multiple and raised or lowered as desired.

Draft. The front end must be regarded as an apparatus for doing work. It receives power for doing this work from the exhaust steam from the cylinders. The work which it performs consists in drawing air through the ash pan, grates, fire, fire door, and other openings, then continues its work by drawing the gases of combustion through the flues of the boiler into the front end, then forcing them out through the stack into the atmosphere. In order that this work may be accomplished, a pressure less than the atmosphere must be maintained in the smoke-box. This is accomplished through the action of the exhaust jet in the stack. The difference in pressure between the atmosphere and the smoke-box is called *draft.*

Under the conditions of common practice, the exhaust jet does not fill the stack at or near the bottom but touches the stack only when it is very near the top. The action of the exhaust jet is to entrain the gases of the smoke-box. A jet of steam flowing steadily from the exhaust tip when the engine is at rest produces a draft that is in every way similar to that obtained with the engine running. The jet acts to induce motion in the particles of gas which immediately surround it and also to enfold and to entrain the gases which are thus made to mingle with the substance of the jet itself.

The induced action, illustrated in Fig. 51, is by far the most important. The arrows in this figure represent the direction of the currents surrounding the jet. It will be seen that the smoke-box gases tend to move toward the jet and not toward the base of the stack; that is, the jet by the virtue of its high velocity and by its contact with certain surrounding gases gives motion to the particles close about it and these moving on with the jet make room for other

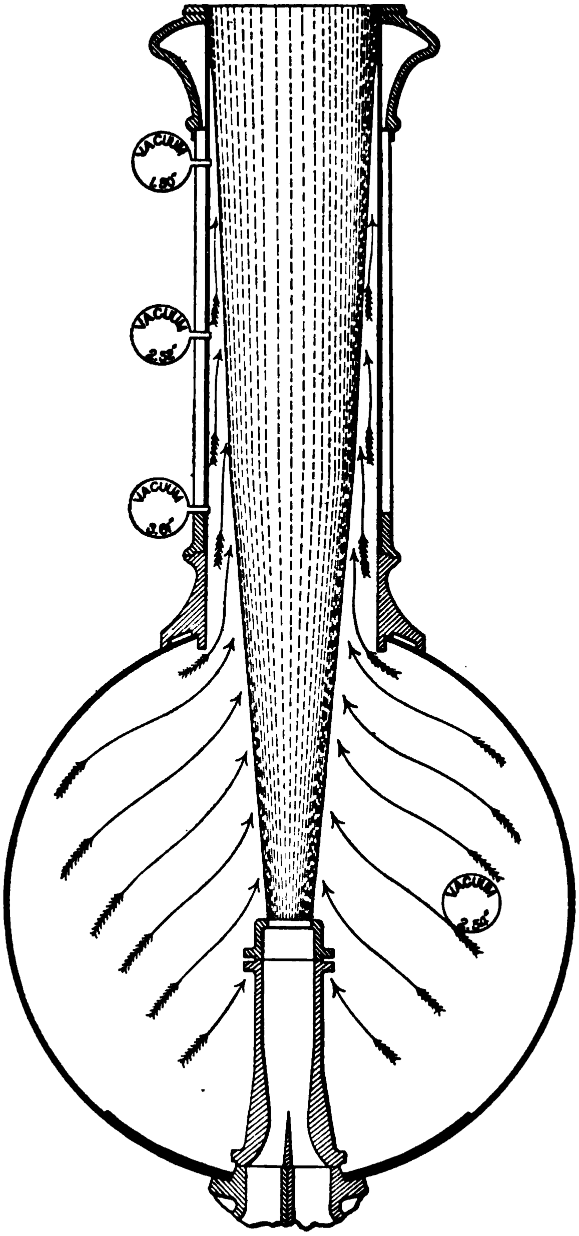


Fig. 51. Section of Exhaust Outlet into Stack, Showing Best Form to Produce Greatest Draft.

particles farther away. As the enveloping stream of gas approaches the top of the stack its velocity increases and it becomes thinner. The vacuum in the stack decreases towards the top. Thus the jet in the upper portion of the stack introduces a vacuum in the lower portion just as the jet as a whole induces a vacuum in the smoke-box.

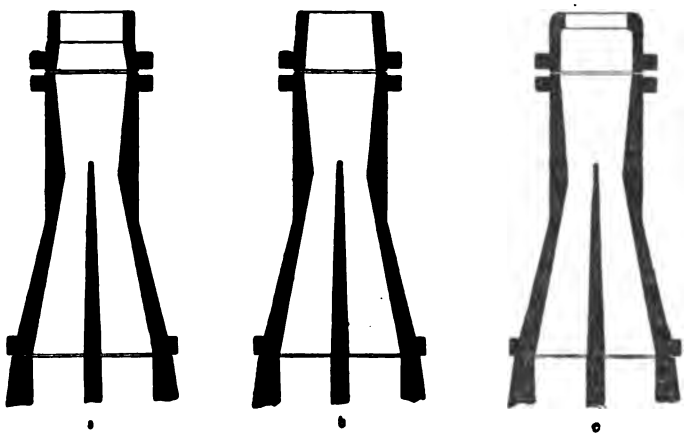


Fig. 52. Forms of Exhaust Nozzles.

It will be found that the highest vacuum is near the base of the stack. It is higher than the smoke-box on account of the large volume of gas in the latter and it grows less toward the top of the stack. This is illustrated by the different gauges shown in Fig. 51.

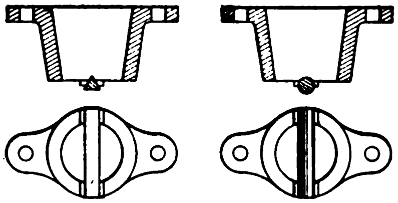


Fig. 53. Bridges Placed Across Exhaust Nozzles.

Exhaust Nozzles. It has been determined by experiment that the most efficient form of exhaust nozzle is that which keeps the jet in the densest and most compact form. Tests indicate that the nozzle giving the jet the least spread is the most efficient. Of the three forms of exhaust nozzles shown in Fig. 52, the spread of the jet is least for *a* and most for *c*. Nozzle *a* ends in a plain cylindrical portion 2 inches in length. Nozzle *c* is contracted in the form of a plain cylinder engine in an abrupt cylindrical contraction. It has been common practice, in cases where engines refuse to steam properly, to put across the exhaust nozzles round or knife-shaped bridges as indicated in Fig. 53. The use of bridges accomplishes the desired result but experiments have shown that this method materially affects the efficiency of the engine because of the increase of back pressure in the cylinders. It is, therefore, best not to split up the jet by using a bridge in cases where the draft is unsatisfactory, as the desired results may be obtained by reducing the diameter of the exhaust nozzle.

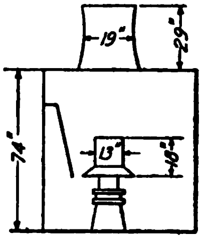


Fig. 54. Best Proportions for Single Draft Pipe and Stack.

As previously stated, draft or petticoat pipes are used for the purpose of increasing the draft or vacuum in the front end and in the tubes. A great many tests have been made under the supervision of the Master Mechanics' Association to determine the proper proportions of the petticoat pipes and their best relative position with reference to the stack and exhaust nozzle.

The report of the committee of the Master Mechanics' Association with reference to single draft pipes states "that for the best results, the presence of a draft pipe requires a smaller stack than would be used without it but that no best combination of single draft pipe and stack could be found which gave a better draft than could be obtained by the use of a properly proportioned stack without the draft pipe. While the presence of a draft pipe will improve the draft when the stack is small it will not do so when the stack is sufficiently large to serve without it. The best proportion and adjustment of a single draft pipe and stack are shown in Fig. 54."

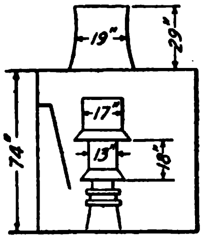


Fig. 55. Best Proportions for Double Draft Pipe and Stack.

The finding of the same committee with reference to the use of the double draft pipes is as follows: "Double draft pipes of various diameters and lengths and having many different positions within the front ends all in combination with stacks of different diameters, were included in the experiments with results which justify a conclusion similar to that reached with reference to single draft pipes. Double draft pipes make a small stack workable. They cannot serve to give a draft equal to that which may be obtained without them provided the plain stack is suitably proportioned. The arrangements and proportions giving the best results are illustrated in Fig. 55."

Stack. The stack is one of the most important features of the front end. Many different forms and proportions of stacks have been employed but at the present time only two general types are found in use to any great extent, namely, the *straight* and *tapered stacks.*

In connection with tests conducted in the Locomotive Testing Laboratory at Purdue University, it has been found that the tapered stack gives much better draft values than the straight stack. It was also found that the effect on the draft due to minor changes of proportion, both of the stack itself and the surrounding mechanism, was least noticeable when the tapered stack was used than was the case with the straight stack. A variation of one or two inches in the diameter of the tapered stack or height of the exhaust nozzle affected the draft less than similar changes with a straight stack. For these reasons, the tapered stack was recommended in preference to the straight stack. By the term *tapered stack* as herein referred to, is meant a stack having its least diameter or choke 16½ inches from the bottom, and a diameter above this point increasing at the rate of two inches for each additional foot.

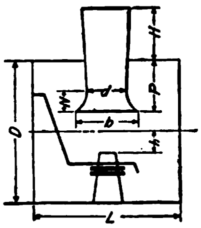


Fig. 56. Arrangement of Nozzle and Stack.

The diameter of any stack designed for best results is affected by the height of the exhaust nozzle. As the nozzle is raised, the diameter of the stack must be reduced and as the nozzle is lowered, the diameter of the stack must be increased. From the facts mentioned above, it can be seen there exists a close relation between the exhaust nozzle, petticoat pipe, stack, and the diaphragm; hence a standard front end arrangement has been recommended and is presented herewith.

The best arrangement of front end apparatus is shown in Fig. 56, in which

H = height of stack above boiler shell in inches
D = diameter of shell in inches
L = length of the front end in inches
P = the distance in inches stack extends into the smoke-box

N = distance in inches from base of stack to choke
b = width of stack in inches at the base
d = diameter of stack in inches at the choke
h = distance in inches of the nozzle below the center line of smoke-box

In order to obtain the best results, H and h should be made as great as possible while the other principal dimensions should be as follows:

$d = .21\ D + .16\ h$
$b = 2\ d$ or $.5\ D$
$P = .32\ D$
$N = .22\ D$

Rate of Combustion. It is a well-known fact that each pound of fuel is capable of giving out a certain definite amount of heat. Therefore, the more rapid the combustion, the greater the amount of heat produced in a given time. In stationary boilers, where the grate is practically unlimited, the rate of combustion per square foot of grate area per hour varies from 15 to 25 pounds. In locomotives, however, where the grate area is limited, the fuel consumption is much greater, rising at times as high as 200 pounds per square foot of grate area per hour. This rapid combustion results in a great loss of heat and a reduction in the amount of water evaporated per pound of coal. It has been shown that when coal is burned at the rate of 50 pounds per square foot of grate area per hour, 8¼ pounds of water may be evaporated for each pound of coal. While if the rate of combustion is increased to 180 pounds per square foot of grate area per hour, the evaporation will fall off to about five pounds, a loss of water evaporated per pound of coal of nearly 40 per cent. This loss may be due to a failure of the heating surface to absorb properly the increased volume of heat passing over them, or to the imperfect combustion of the fuel on the grate, or it may be due to a combination of these causes.

The results of experiments show that the lower the rate of combustion the higher will be the efficiency of the furnace, the conclusion being that very high rates of combustion are not desirable and consequently that the grate of a locomotive should be made as large as possible so that exceptionally high rates of combustion will not be necessary.

With high rates of combustion, the loss by sparks is very serious and may equal in value all of the losses occurring at the grate. Fig. 57 is a diagram representing the losses that occur, due to an increase in the rate of combustion. The line *a b* illustrates graphically the amount of water evaporated per pound of coal for the various rates of combustion. Thus, with a rate of 50 pounds per square foot of grate area per hour, 8¼ pounds of water are evaporated. When the rate of combustion is raised to 175 pounds, only about 5⅓ pounds of water are evaporated. It is thus seen that the efficiency of the locomotive from the standpoint of water evaporated per pound of coal decreases as the rate of combustion per square foot of grate area increases. If it could be assumed that the heat developed in the furnace would be absorbed with the same degree of completeness for all rates of combustion, the evaporation would rise to the line *a c*. If, in addition to this, it could be assumed that there were no spark losses, the evaporation would rise to the line *a d*. Finally, if in addition to these, it could be assumed that there were no losses by the excess admission of air or by incomplete combustion, then the evaporation would remain constant for all rates of combustion and would be represented by the line *a e*. That is, with the boiler under normal

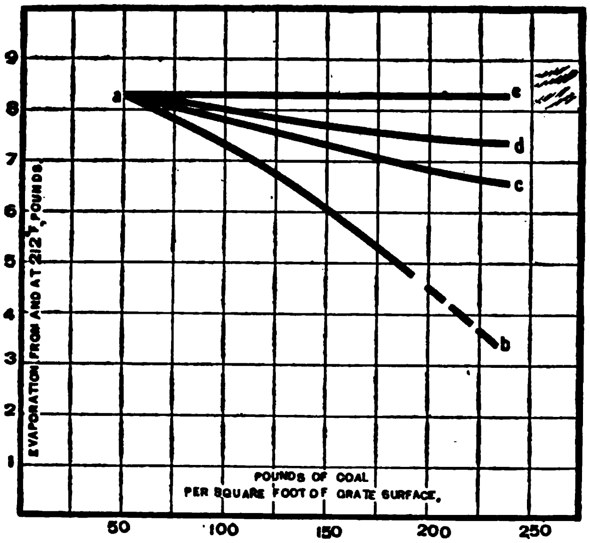


Fig. 57. Curves Showing Losses Due to Increases in Rate of Combustion.

conditions, the area *a b c* represents the loss occasioned by deficient heating surface; the area *a c d* represents that caused by spark losses; and the area *a d e* represents that due to excessive amounts of air and by imperfect combustion.

Spark Losses. From the diagram shown in Fig. 57, it is evident that one of the principal heat losses is that of sparks. By the term *sparks* is meant the small particles of partially burned coal which are drawn through the flues and ejected through the stack by the action of the exhaust. In the operation of a locomotive, it has been demonstrated that the weight of sparks or cinders increases with the rate of combustion and may reach a value of from 10 to 15 per cent of the total weight of coal fired. Damage suits frequently arise, due to fires started by cinders thrown from the stack of the locomotive. Experiments have shown, however, that sparks from a locomotive will not be likely to start fires beyond the right of way.

High Steam Pressures. With the development of high-power locomotives came the use of high steam pressures. At first, only very low pressures were carried but soon 200 pounds pressure per square inch became very common and 220 and 225 not unusual. But with the increase of pressure there came an increase in trouble due to bad water, leaky flues, and an increase in incidental leaks in the boiler. All of these factors affected the performance of the locomotive. To determine to what extent the economic performance of the boiler was affected by an increase of steam pressure and also the most economical steam pressure to use, a series of tests were carried out at Purdue University. The following are the conclusive results as read before the Western Railway Club by Dean W. F. M. Goss:

THE EFFECT OF DIFFERENT PRESSURES UPON BOILER PERFORMANCE

1. The evaporative efficiency of a locomotive boiler is but slightly affected by changes in pressure between the limits of 120 pounds and 240 pounds.
2. Changes in steam pressure between the limits of 120 pounds and 240 pounds will produce an effect upon the efficiency of the boiler which will be less than one-half pound of water per pound of coal.
3. It is safe to conclude that changes of no more than 40 or 50 pounds in pressure will produce no measurable effect upon the evaporative efficiency of the modern locomotive boiler.

THE EFFECT OF DIFFERENT PRESSURES UPON SMOKE-BOX TEMPERATURES

1. The smoke-box temperature falls between the limits of 590 degrees F. and 850 degrees F., the lower limit agreeing with the rate of evaporation of 4 pounds per foot of heating surface per hour and the higher with a rate of evaporation of 14 pounds per square foot of heating surface per hour.

2. The smoke-box temperature is so slightly affected by changes in steam pressure as to make negligible the influence of such changes in pressure for all ordinary ranges.

CONCLUSIONS

1. The steam consumption under normal conditions of running has been established as follows:

Boiler Pressure	Steam per Horse-Power Hour
120	29.1
140	27.7
160	26.6
180	26.0
200	25.5
220	25.1
240	24.7

2. The results show that the higher the pressure, the smaller the possible gain resulting from a given increment of pressure. An increase of pressure from 160 to 200 pounds results in a saving of 1.1 pounds of steam per horse-power per hour while a similar change from 200 pounds to 240 pounds improves the performance only to the extent of .8 of a pound per horse-power hour.

3. The coal consumption under normal conditions of running has been established as follows:

Boiler Pressure	Coal per Horse-Power Hour
120	3.84
140	3.67
160	3.53
180	3.46
200	3.40
220	3.35
240	3.31

4. An increase of pressure from 160 to 200 pounds results in a saving of 0.13 pounds of coal per horse-power hour while a similar change from 200 to 240 results in a saving of but 0.09 pounds.

5. Under service conditions, the improvement in performance with increase of pressure will depend upon the degree of perfection attending the maintenance of the locomotive. The values quoted in the preceding paragraphs assume a high order of maintenance. If this is lacking, it may easily

happen that the saving which is anticipated through the adoption of higher pressures will entirely disappear.

6. The difficulties to be met in the maintenance both of boiler and cylinders increase with increase of pressure.

7. The results supply an accurate measure by which to determine the advantage of increasing the capacity of a boiler. For the development of a given power, any increase in boiler capacity brings its return in improved performance without adding to the cost of maintenance or opening any new avenues for incidental losses. As a means of improvement it is more certain than that which is offered by increase of pressure.

8. As the scale of pressure is ascended an opportunity to further increase the weight of a locomotive should in many cases find expression in the design of a boiler of increased capacity rather than in one of higher pressures.

9. Assuming 180 pounds pressure to have been accepted as standard and assuming the maintenance to be of the highest order, it will be found good practice to utilize any allowable increase in weight by providing a larger boiler rather than by providing a stronger boiler to permit higher pressures.

10. Whenever the maintenance is not of the highest order, the standard running pressures should be below 180 pounds.

11. Where the water which must be used in boilers contains foaming or scale-making admixtures, best results are likely to be secured by fixing the pressure below the limit of 180 pounds.

12. A simple locomotive using saturated steam will render good and efficient service when the running pressure is as low as 160 pounds. Under most favorable conditions, no argument is to be found in the economical performance of a machine which can justify the use of pressures greater than 200 pounds.

Heating Surface. While the points thus far considered are more or less important in their bearing in the generation of steam, yet the amount of heating surface is, as a rule, the most important. As previously stated, the lower the rate of combustion per square foot of heating surface, the higher will be the rate of evaporation per pound of coal. The ratio of the heating surface of the flues to that of the firebox varies greatly, in some cases being only 9 to 1 while in others it is found as great as 18 to 1. There is perhaps a correct value for this ratio, but at the present time it is unknown. The relation existing between the total heating surface and the grate area varies between wide limits for different cases. Table III, taken from the Proceedings of the Master Mechanics' Association for 1902, gives the ratio of heating surface to grate area in passenger and freight locomotives burning various kinds of fuel.

TABLE III

Ratio of Heating Surface to Grate Area

Fuel	Passenger Locomotive		Freight Locomotive	
	Simple	Compound	Simple	Compound
Free Burning Bituminous	65 to 90	75 to 95	70 to 85	65 to 85
Average Bituminous	50 to 65	60 to 75	45 to 70	50 to 65
Slow Burning Bituminous	40 to 50	35 to 60	35 to 45	45 to 50
Bituminous, Slack, and Free Burning Anthracite	35 to 40	30 to 35	30 to 35	40 to 45
Low Grade Bituminous, Lignite, and Slack	28 to 35	24 to 30	25 to 30	30 to 40

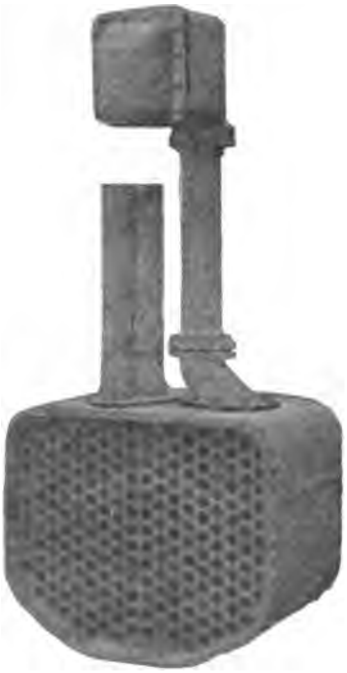
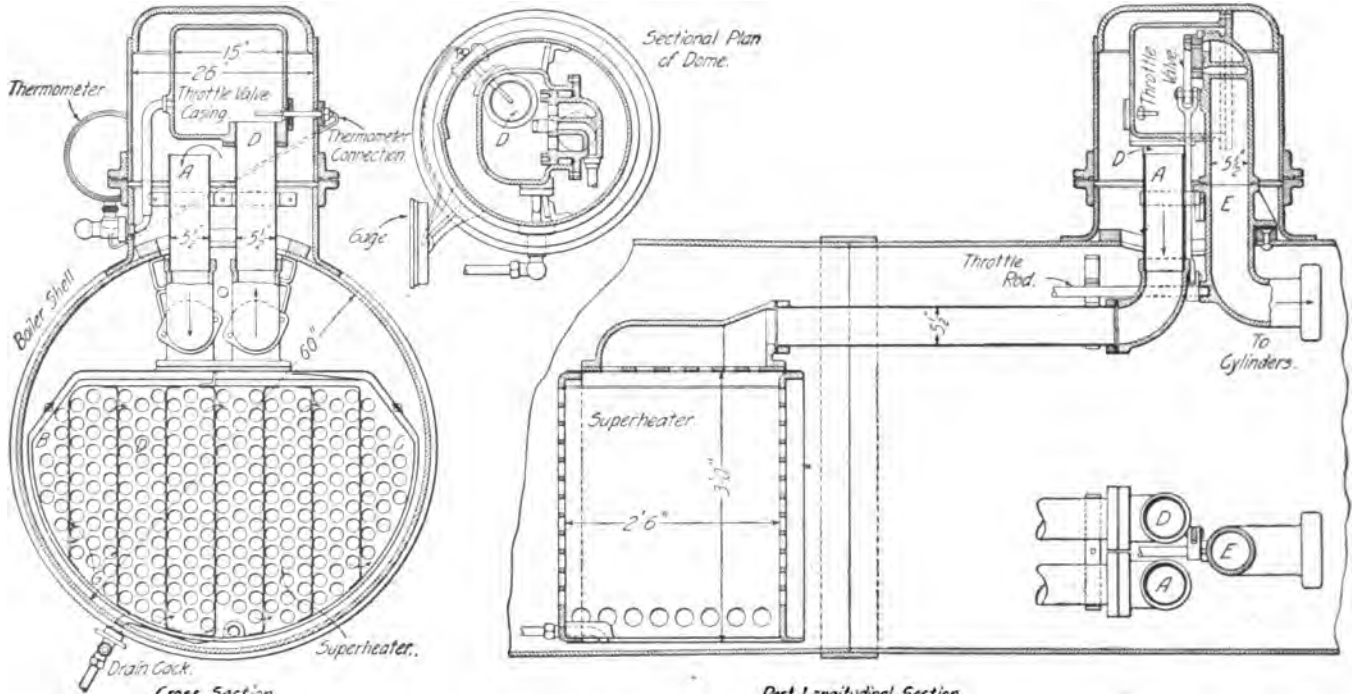


Fig. 58. Pielock Superheater.

From the foregoing, it is evident that it is exceedingly difficult to determine just how much heating surface a locomotive boiler should have to give the best results. As a rule, they are made as large as possible so long as the total allowable weight of the locomotive is not exceeded. This is not, however, a scientific rule to follow but it is safe to say that the value of no locomotive has ever been impaired by having too much heating surface. The greater the boiler power, the higher will be the speed which can be maintained. It is important that the boiler be covered with a good lagging in order to prevent loss of heat due to radiation.

Superheaters. In recent years there has been added to the locomotive and used in the United States to a certain limited extent a superheater. A superheater consists of a series of tubes and headers



Cross Section.

Part Longitudinal Section.

Fig. 59 Details of Pielock Superheater.

usually placed in the smoke-box, through which steam passes on its way from the boiler to the cylinders. By the use of the superheater, additional heat is imparted to the steam as it passes from the dry pipe to the cylinders. As the steam comes from the dry pipe it is known as *saturated steam,* that is, steam containing a small amount of moisture. If more heat is given to the steam, its temperature is raised, the pressure remaining unchanged. Steam thus heated becomes more like a gas and possesses a large amount of heat energy which is available for doing work. Since this additional energy is secured from the waste gases which pass out of the stack, the economy of the locomotive will be improved. Locomotives equipped with superheaters show a considerable saving in the amount of coal and water used. A brief description of the more important types of superheaters is as follows:

Pielock Superheater. The Pielock superheater, illustrations of which are shown in Fig. 58 and Fig. 59, is found in use on a number of railways in Germany and in Italy, and also on the Hungarian State Railways. Its construction consists of a box containing tube plates corresponding to those of the boiler, the box being set in the boiler barrel so that the flues pass through it. It is placed at such a distance from the fire-box as will prevent the tubes from becoming overheated. The vertical baffle plates *G* between the rows of tubes cause the steam to follow a circuitous path passing up and down between the tubes. The steam from the dome passes down the open pipe *A*, Fig. 59, to the left-hand chamber *B*, then transversely to the several chambers as shown by arrows until it reaches the right-hand chamber *C*. From the chamber *C* it passes up through the pipe *D* to the chamber enclosing a throttle valve from which it enters the steam pipe *E*.

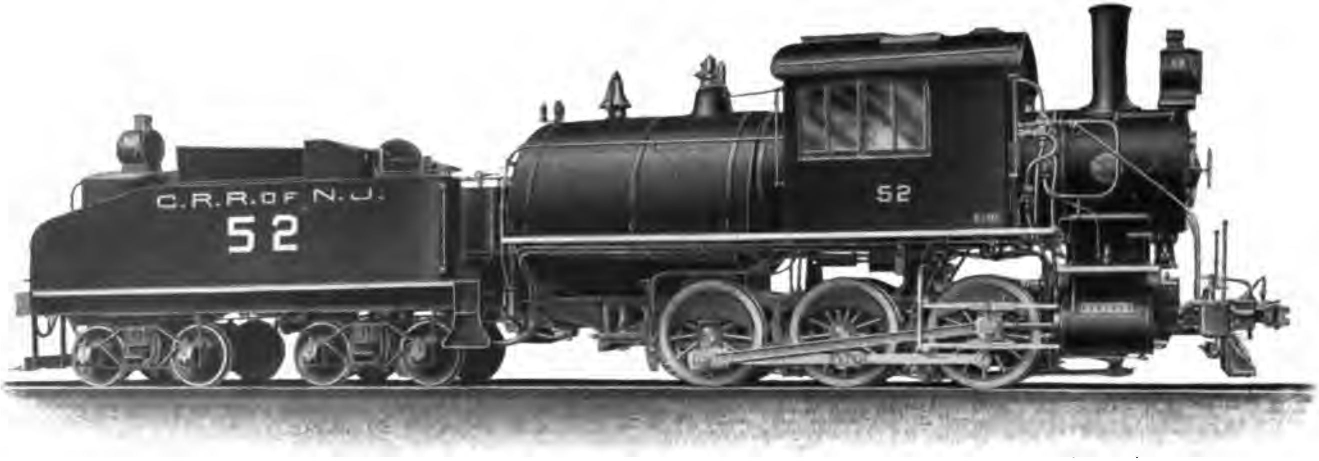
In installing the superheater, the boiler tubes are first set in place in the superheater and then placed in the boiler, the smoke-box tube plate being left off for this purpose. The tubes are first expanded into the fire-box or back flue-sheet, then in the superheater plates (for which a special mandrel is used), and finally in the front flue-sheet. A blow-off cock extends from the bottom of the superheater through the boiler by means of which any leaks in the superheater may be detected. A gauge at the bottom indicates the degree of superheat of the steam in the throttle valve chamber.

This type of superheater can be applied to a locomotive without making any alteration since the superheater is built to fit the boiler in which it is to be used. It does not interfere with the cleaning of the flues or the washing out of the boiler. It is reported that by the use of this superheater a saving in coal of about 15 to 18 per cent and in water of about 20 per cent, is effected.

Schmidt Superheater. The Schmidt superheater is another type which is largely used on German railroads. Its construction is based on entirely different principles from those of the Pielock superheater. It differs from the Schenectady or Cole superheater in details only.

Schenectady or Cole Superheater. The Schenectady superheater was developed by the American Locomotive Company. It has had a large application in recent years and good results are being obtained. The general arrangement and construction of this superheater is shown in Fig. 60 and Fig. 61.

The use of bent tubes and the necessity for dismantling the whole apparatus in order to repair a single leaky boiler tube gave rise to many objections to the use of superheaters. In the construction of the Schenectady superheater, many of the objectionable features have been eliminated. By reference to Fig. 60, it will be seen that steam entering the T-pipe from the dry pipe *A* is admitted to the upper compartment only. To the front side of the T-pipe are attached a number of header castings *B*, the joint being made with copper wire gaskets, as in steam chest practice. Each header casting is subdivided into two compartments by a vertical partition shown in cross-section at *C*. Five tubes each $1\frac{1}{16}$ inch outside diameter are inserted through holes (subsequently closed by plugs) in the front wall of each header casting. These tubes having first been expanded, special plugs are firmly screwed into the vertical partition wall and are enclosed by five $1\frac{3}{4}$-inch tubes which are expanded into the rear wall of the header casting in the usual way. Each nest of two tubes is encased by a regular 3-inch boiler tube which is expanded into the front and back tube sheets as usual. The back end of each inner tube is left open and the back end of each middle tube is closed. The back ends of the two tubes are located about 36 inches forward from the rear flue sheet. The arrangement of the three flues is shown in Fig. 61. The inner tube is allowed to drop and rest on the bottom of the middle tube while the end of the middle tube is so constructed



SIX-WHEEL TYPE OF SWITCHING LOCOMOTIVE, BUILT FOR THE CENTRAL RAILROAD OF NEW JERSEY
American Locomotive Co.

as to support both the inner and middle tubes in the upper part of the 3-inch tube, thus leaving a clear space below.

As can be seen from Fig. 60, steam from the dry pipe enters the forward compartments of each of the header castings, passes back through each of the inner tubes, thence forward through the annular space between the inner and middle tubes, through the rear compartments of each of the header castings, and thence into the lower compartment of the T-pipe, thence by the right and left steam pipe *D* and *E* to the cylinders. The steam in passing through the different channels is superheated by the smoke-box gases and products of combustion. In this particular design, fifty-five 3-inch tubes are employed, thus displacing as many of the regular smaller tubes as would occupy a similar space.

It is necessary to provide some means by which the superheater

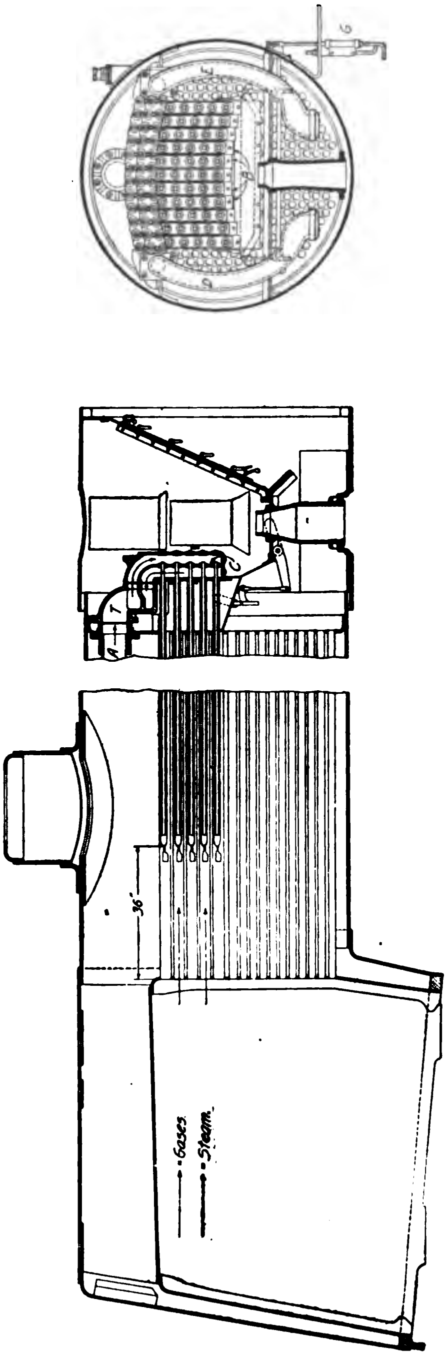


Fig. 60. Details of Schenectady or Cole Superheater.

tubes shall be protected from excessive heat when steam is not being passed through them. In this instance, this is accomplished by the automatic damper shown in Fig. 60. The entire portion of the smoke-box below the T-pipe and back of the header castings is completely enclosed by metal plates. The lower part of this enclosed box is provided with a damper which is automatic in its action. Whenever the throttle is opened and steam is admitted to the steam chest, the piston of the automatic damper cylinder *G* is forced upward and the damper is held open, but when the throttle is closed, the spring immediately back of the automatic damper cylinder closes the damper and no heat can be drawn through the 3-inch tubes. In this way, the superheater tubes are prevented from being burned. There is a slight loss of heating surface in introducing the group of 3-inch tubes and applying a superheater, but this loss is more than offset by the gain in economy due to the use of the superheated steam.

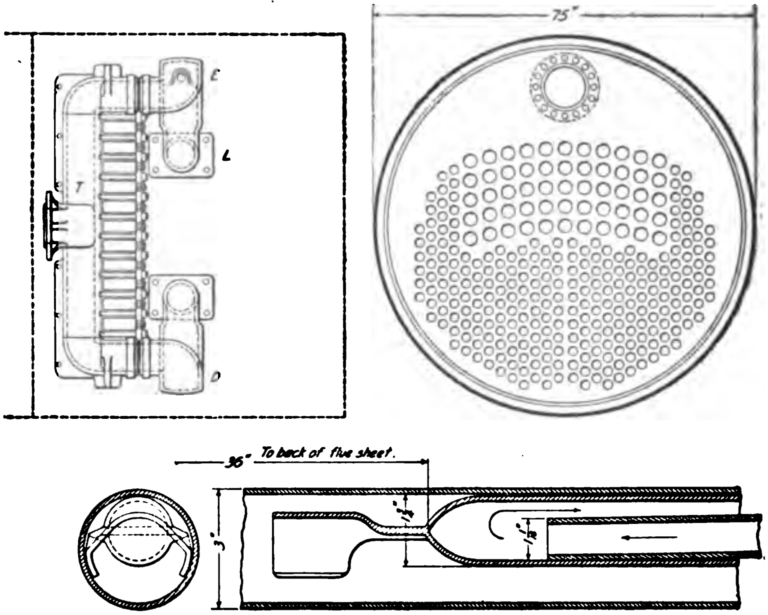


Fig. 61. Further Details of Cole Superheater.

The results of laboratory tests of the Schenectady superheater indicate a saving of from 14 to 20 per cent of water and from 5 to 12 per cent of coal.

Baldwin Superheater. The Baldwin superheater which is now being used by some railroads differs from the Schenectady and the Pielock superheaters in that it is found entirely within the smoke-box. It can be applied to any locomotive without disturbing the boiler and its application does not reduce the original heating surface.

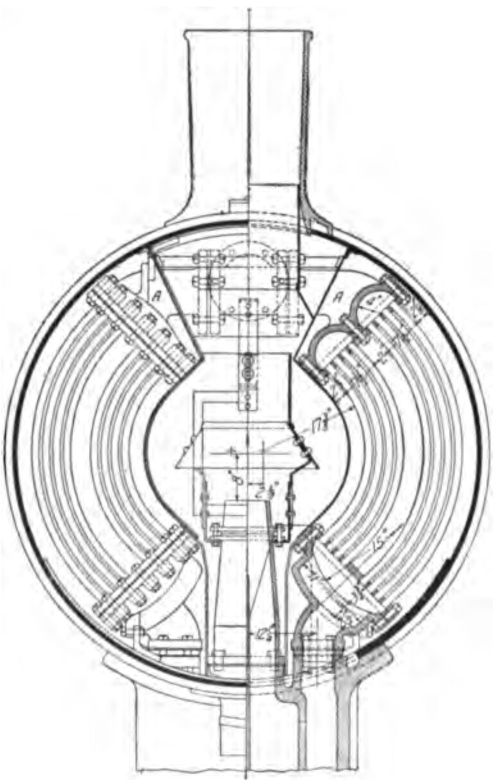


Fig. 62. Baldwin Superheater.

It consists of two cast-steel headers *A*, Fig. 62, which are cored with proper passages and walls. These headers are connected by a large number of curved tubes which follow the contour of the smoke-box shell, and are expanded in tube plates bolted to the headers. The curved tubes are divided into groups, the passages in the headers being so arranged that the steam after leaving the T-head on either side passes down through the group forming the outer four rows of the rear section of superheater tubes, then crosses over in the lower header and passes up through the inner group of the next section and up through the outer group and thence down through both the inner and outer groups of the forward section and through a passage-way in the lower header to the saddle. As illustrated in Fig. 63, these tubes are heated by the gases from the fire tubes and the deflecting plates are so arranged as to compel these gases to circulate around the tubes on both sides to the front end of

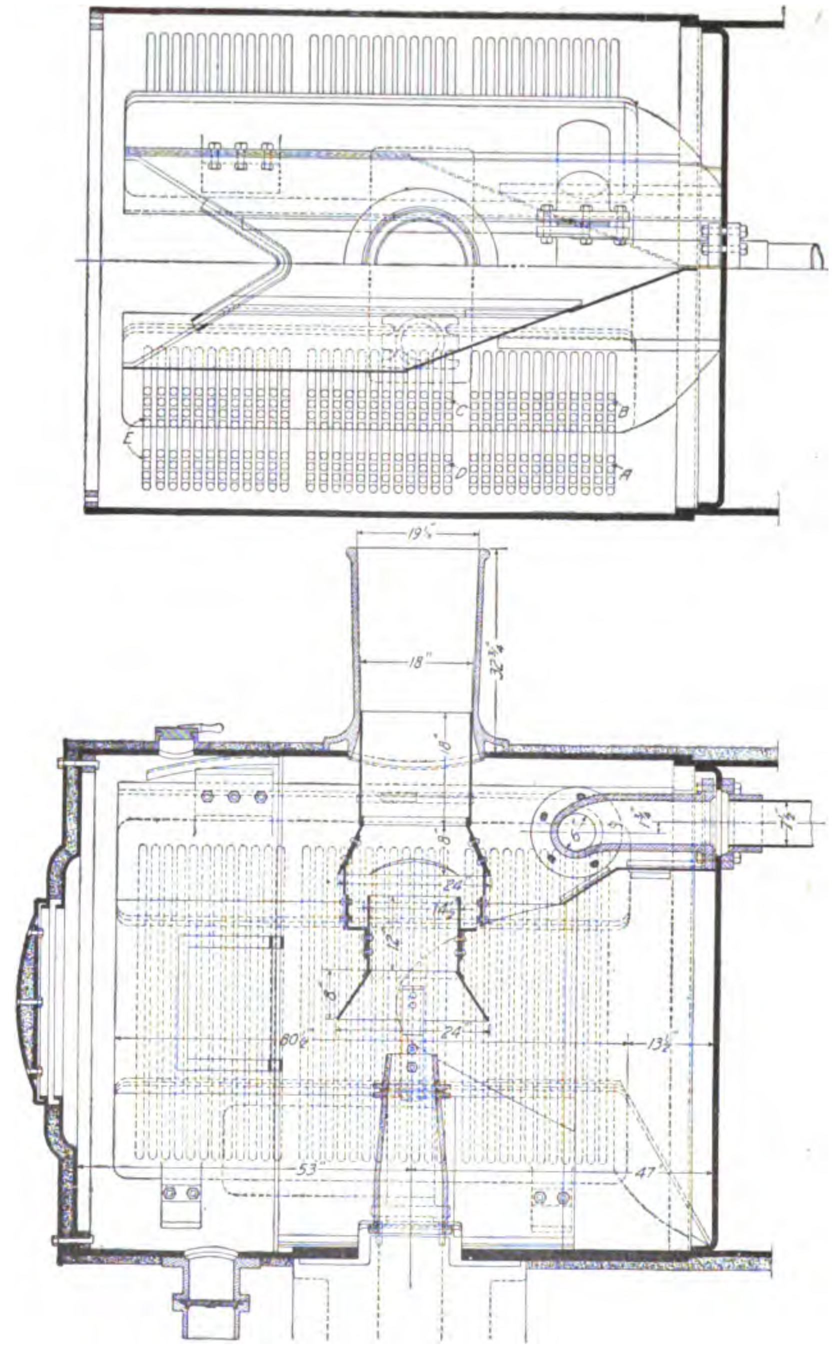


Fig. 63. Side Elevation Baldwin Superheater.

the smoke-box and thence back through the center to the stack. Thus, the superheater uses only such heat as is ordinarily wasted through the stack, and whatever gain in superheat is obtained, is clear gain.

Experiments so far made with this type of superheater show that while it is not possible to obtain a very high degree of superheat, yet enough is obtained to very decidedly increase the economy of the boiler. The front end is heavily lagged at all points to prevent as far as possible all loss of heat by radiation.

There have been several types of superheaters placed on the market in addition to those already mentioned, all having more or less merit. They differ in detail of construction but the principle embodied is covered by some one of the types described in the preceding pages.

Locomotive Boiler Design. The design of locomotive boilers and engines is a very deep subject—one requiring much thought and study. Limited space prevents going into a discussion of the reasons for the adoption of different designs. The following formulae for the calculation of thickness of plates, spacing of rivets, etc., are given. Some of these formulae, while being semi-empirical, are based on theoretical assumptions and represent modern practice in the design of parts mentioned. In figuring the thickness of the boiler shell, the following formula is given:

$$t = \frac{P\,D\,f}{2\,T\,E}$$

where

t = thickness of shell in inches

P = steam pressure, pounds per square inch

D = inside diameter of shell in inches

f = factor of safety, usually taken not less than $4\frac{1}{2}$

T = tensional strength of plate in pounds per square inch, usually taken as 55,000

E = efficiency of longitudinal joint expressed as a decimal fraction which may be taken as .85

Example. In a given locomotive boiler, the first ring is 60 inches in diameter; the steam pressure is 200 pounds. Required the thickness of the plate.

Solution.

$$t = \frac{200 \times 60 \times 4.5}{2 \times 55000 \times .85}$$
$$= .57 \text{ inches}$$

The efficiency of the joint is expressed as follows:

$$E = \frac{\text{Tearing resistance of joint}}{\text{Tearing resistance of solid plate of same dimensions}}$$

or

$$E = \frac{\text{Shearing resistance of joint}}{\text{Shearing resistance of solid plate of same dimensions}}$$

Note: Use whichever value is the least.

In computing the thickness of the conical connection in a boiler shell use the formula

$$t = \frac{P\,D\,f}{2\,T\,E}$$

the inside diameter at the large end being considered.

In calculating the thickness of the fire-box side and fire-door sheets, the following formula may be used:

$$t = \sqrt{\frac{2\,a^2\,P}{49500}}$$

where a = the pitch of stay-bolts in inches.

The pitch of the stay-bolts may be taken as

$$a = \sqrt{\frac{49500\,t^2}{2\,P}}$$

Example. Determine the thickness of the side sheets when the steam pressure employed is 200 pounds per square inch and the stay-bolts are spaced 4 inches from center to center.

Solution.

$$t = \sqrt{\frac{2 \times 4^2 \times 200}{49500}}$$
$$= .36 \text{ inches}$$

The safe tensile strength of stay-bolts should be taken not to exceed 5,500 pounds per square inch.

The diameter of rivets may be determined by the following formula:

$$d = 1.2\sqrt{t}$$

The following standard thicknesses of plates are used in locomotive boiler construction: Crown sheet, side sheet, and back firebox sheet, $\frac{3}{8}$ inch in thickness; for boiler pressures not exceeding 200 pounds, the boiler head, roof, sides, and dome, $\frac{1}{2}$ inch thick, while for boilers with steam pressures between 200 and 240 pounds, these plates are $\frac{9}{16}$ inch thick.

In designing the riveted joints, their strength must be considered from several different standpoints. It must be sufficiently strong to withstand the tensional stress on the metal contained in the plate between the rivets. The plates must be of such thickness as will safely carry the compressional stresses behind the rivets and the rivets must be placed in rows sufficiently far apart and far enough from the edge of the plate to insure against shearing or tearing out of the metal. In the formulae for the design of a riveted joint, the following notation will be used:

d = diameter of rivet hole in inches
p = pitch or distance in inches between center to center of rivets
t = thickness of plate in inches
h = distance in inches from edge of plate to center of first rivet hole
T = tensile strength of plate in pounds per square inch, usually taken as 55,000
S = shearing strength of rivets in pounds per square inch, usually taken as 55,000
R = shearing strength of plate in pounds per square inch, usually taken as 45,000 pounds per square inch
C = crushing strength of plate in pounds per square inch, usually taken as 50,000 pounds per square inch
f = factor of safety usually taken not less than $4\frac{1}{2}$

The safe resistance in pounds per square inch offered by one rivet to shear

$$= .7854\, d^2 \frac{S}{f}$$

The safe resistance in pounds per square inch offered to tearing of plate between rivet holes

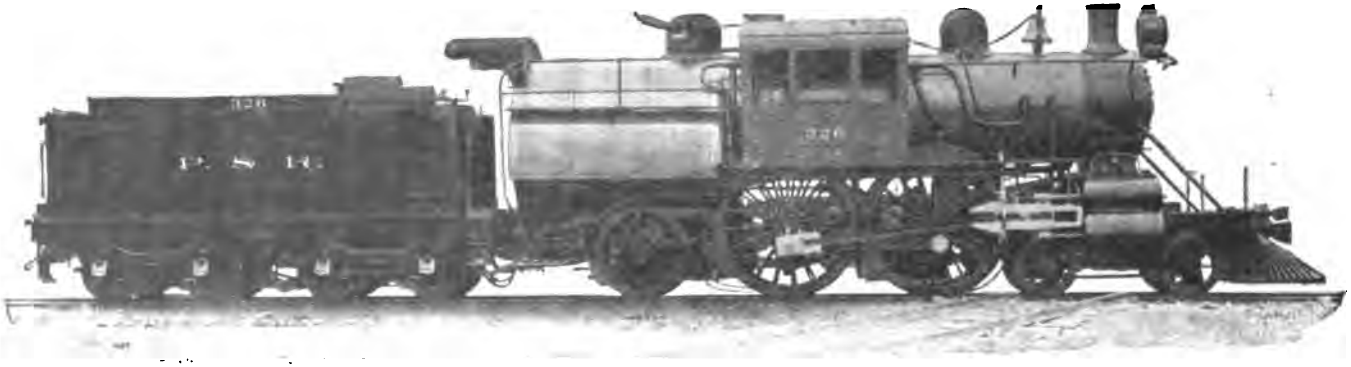
$$= (p-d)\,t\,\frac{T}{f}$$

The safe resistance to crushing in pounds per square inch of the portion of the plate in front of rivet

$$= \frac{t\,d\,C}{f}$$

The safe resistance to shearing out in pounds per square inch of that portion of the plate in front of the rivet

$$= \frac{2\,h\,t\,R}{f}$$



FAST PASSENGER COMPOUND LOCOMOTIVE, BALDWIN LOCOMOTIVE WORKS—Total weight of engine 86 tons.

LOCOMOTIVE BOILERS AND ENGINES

PART II

THE LOCOMOTIVE ENGINE

In studying the conditions affecting the performance of the engine proper, the amount of lead, outside lap, and inside clearance must be taken into consideration.

Lead. By *lead* is meant the amount the steam port is open when the engine is on *dead center* or when the piston is at the beginning of its stroke. This amount varies from 0 to ¼ of an inch in practice. By having the proper amount of lead, a sufficient amount of steam behind the piston is assured at the beginning of the stroke and assists in maintaining the steam pressure until the steam port is closed and the steam is thereby cut off. It also serves to promote smooth running machinery. Any admission of steam behind the piston before the end of the stroke results in negative work, hence the amount of lead should be limited and largely controlled by the speed of the machine.

Outside Lap. By the term *outside lap* is meant the amount the valve overlaps the outside edges of the steam ports when it is in its central position. One of the effects of increasing outside lap is to cause cut-off to take place earlier in the stroke, other conditions remaining unchanged. If, however, the amount of lap is increased and it is desired to maintain the same cut-off, the stroke of the valve must be increased. Within certain limits, outside lap increases the rapidity with which the valve opens the steam port, resulting in a freer admission of steam. The range of cut-off is decreased as the lap is increased, other conditions remaining the same.

When the cut-off is short, the exhaust is hastened, an effect which diminishes as the cut-off is lengthened. The amount by which the steam port is uncovered by the exhaust cavity of the slide valve is

Copyright, 1909, American School of Correspondence.

increased as the cut-off is shortened. Other things remaining constant the changing of any one of the events of stroke causes a corresponding change to a greater or less degree of each of the other events.

Inside Clearance. By the expression *inside clearance* is meant the amount the steam port is uncovered by the exhaust cavity of the valve when the valve is in its central position. Formerly it was customary to have an inside lap of about $\frac{1}{16}$ of an inch but in recent years in the development of engines which require a free exhaust at high speeds, the inside lap was reduced until now there is in some cases from $\frac{1}{8}$ to $\frac{3}{16}$ inches inside clearance. The effect of changing a valve from inside lap to inside clearance, other things remaining unchanged, is to hasten release and delay compression and hence to increase the interval in which the exhaust port remains open. It also permits a greater extent of exhaust port opening. As a consequence, the exhaust is freer and the back pressure is reduced, giving an advantage in the operation of the engine, which is desired at high speeds. Experiments have shown that an increase in inside clearance for high speeds will bring about an increase in the power of the locomotive, but an increase in inside clearance at slow speeds entails a loss of power and a decrease in efficiency. The loss in power at low speeds, due to inside clearance, is greater at short cut-offs and diminishes as the cut-off is increased. Tests have shown that at moderate speeds, say, 40 to 50 miles per hour, all disadvantages are overcome and much is gained by having inside clearance.

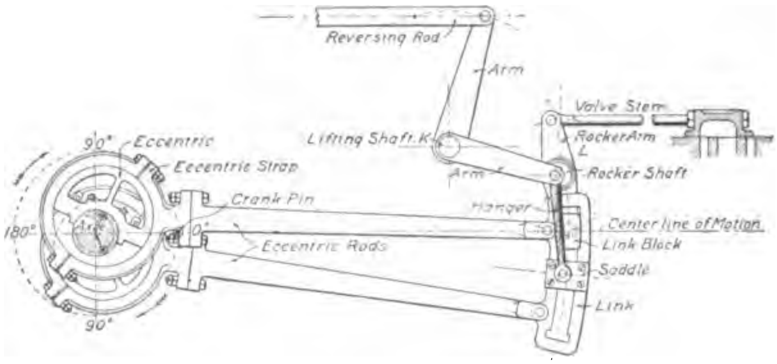


Fig. 64. Standard Stephenson Valve Gear.

Valve Motion. The valve motion of a locomotive engine must meet the following regulations:

1. It must be so constructed as to impart a motion to the valve which will permit the engine to be operated in either direction.

2. It must be operative when the engine is running at a high or low speed and when starting a heavy load.

3. It should be simple in construction and easily kept in order.

Valve Gears. A number of valve gears have been developed which fulfill these requirements more or less satisfactorily, such as the Stephenson, the Walschaert, Joy, and fixed link. The first named is the one most commonly used in the United States. A study will be made of the Stephenson and Walschaert gears, the latter resembling in some respects the Joy valve gear. The Walschaert gear has been extensively used in Europe for many years and of late years has become quite common in America. There are a few modifications of the Stephenson gear which have been made to meet structural requirements but the great majortiy of American engines are fitted with a device as illustrated in Fig. 64. The action of this device is fully explained in the paper on "Valve Gears."

STEPHENSON VALVE GEAR. The several parts comprising the Stephenson gear consists of the reverse lever, reach rod, lifting shaft, link hanger, link, eccentric, and rocker arm.

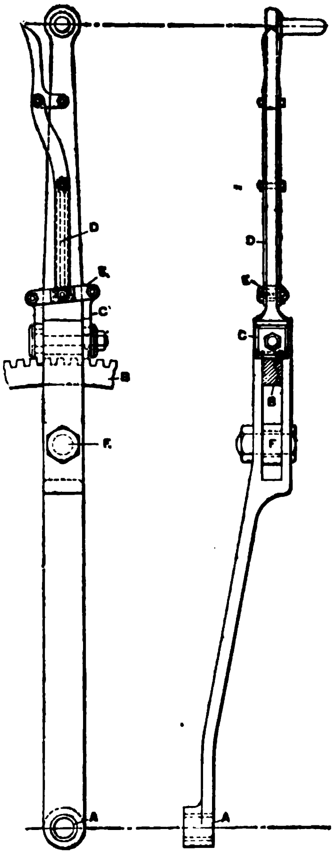


Fig. 65. Reversing Lever.

The *reversing lever* is given a variety of forms, a good design of which is illustrated in Fig. 65. The lever is pivoted at *A*, below the floor of the cab and can be moved back and forth beside the quadrant *B* to which it can be locked by means of the latch *C*. This latch is held down by a spring surrounding the rod *D*, acting on the center of the equalizer *E*. This makes it possible to use very fine graduations of the quadrant and by making the latch as shown, the cut-off can be regulated by practically what amounts to half notches.

The *reach rod*, or *reversing rod*, is fastened to the reversing lever at *F* and consists of a simple piece of flat iron having a jaw at one end by which it serves to connect the reversing lever and the lifting shaft *K*, shown in Fig. 64.

The *lifting shaft*, shown at *K*, Fig. 64, consists of a shaft held in brackets usually bolted to the engine frames to which are connected three arms, one being vertical and to which is attached the reach rod, and two horizontal ones from which the links are suspended.

The *link hanger* is a flat bar with a boss on each end. It carries the link by means of a pin attached to the link saddle, illustrated in Fig. 64.

The *link*, Fig. 64, is an open device held by the saddle and fitted with connections for the eccentric rod.

The *eccentrics*, Fig. 64, usually of cast iron, are fitted to the main driving axle.

The *rocker arm*, Fig. 64, consists of a shaft to which two arms are connected, the lower one of which is attached to the link block and the upper to the valve stem.

Setting the Valves. This is a comparatively simple operation but one requiring great care. On account of the angularity of the rods, it is impossible to adjust any link motion to give equal cut-off at all points for both strokes of the piston. The most satisfactory arrangement is one which provides for an equalization of the lead and cut-off at mid-gear. But even this will cause a variation of cut-off of from ⅜ to ½ of one per cent in the full gear part of the cut-off and at other points.

In setting the valves upon a locomotive, some means must be employed for turning the main driving wheels. This is usually accomplished by mounting the main drivers upon small rollers which can be turned by a ratchet or motor without moving the locomotive as a whole. If a set of rollers are not available, the locomotive may be moved to and fro by using pinch bars.

Before undertaking the setting of the valves, the length of the valve rod must be adjusted. To do this, set the upper rocker arm vertical if the valve seat is horizontal; if inclined, the rocker arm must be placed perpendicular to the plane of the valve seat. Next adjust the length of the valve rod so that it will connect with the rocker arm and the valve when the valve is in its central position. The next step is to locate the dead center points which points give the position of the crank on the dead center. It is very essential that this be done very accurately since a small movement of the crank at this position moves the piston but very little while the same movement causes a comparatively large movement of the valve. Hence, if the dead center points are not accurately located, the valves will not be set so accurately as they otherwise would be. To locate the dead center points, proceed as follows: First, secure a tram *d* as shown in Fig. 66. This tram should be made of a steel rod about ¼ inch in diameter having each end pointed, hardened, and tempered so as to retain a sharp point. With a center punch, make a center *e* on some fixed portion of the frame in such a position that when one point of the tram is in the center *e*, the other pointed end can be made to describe lines on the main driver. To locate the forward dead center, turn the driver ahead until the crank has almost reached the center line as shown in the position *A B*, Fig. 66; that is, when the crosshead is, say, ½ inch from the extreme point of its travel. With the parts in this position, place the tram point in *e* as shown and locate the point *a* on the driver, and describe the line *f f* on the crosshead and guide. Next turn the driver ahead until the crank passes the dead center and the lines *f f* again coincide, when a second point *c* is marked by means of the tram at the same distance from the center of the axle as the point *a*. With a pair of dividers locate the mid-position *b* between *a* and *c*. In setting the valves for the head end, the required dead center will be located when one tram point is in the center *e* and the other in the center *b*. The dead-center point for the back stroke is located in the same manner as just described. An attempt to place the engine on dead center by measurements taken

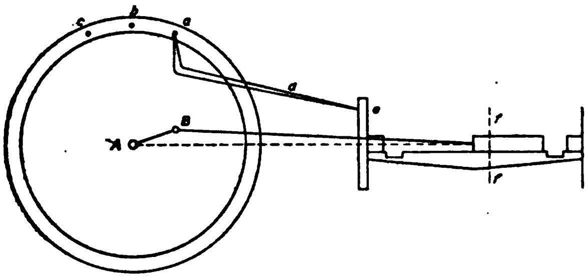


Fig. 66. Diagram for Locating Dead-Center Points.

on the crosshead alone would likely result in an error, since the crank might move through an appreciable angle while passing the dead center and the consequent movement of the crosshead be inappreciable, hence the advisability of using the more exact method explained above is made apparent.

The reverse lever and all the parts having been connected, to set the valves for forward gear, the procedure is as follows: Place the reverse lever in its extreme forward position. When this is done turn the engine ahead until the valve is just beginning to cut off, as shown at *l*, Fig. 67. When this point is reached, stop the engine and make a small punch mark such as *a* on the cylinder casting. Then put one end of the tram *b* into the punch mark and describe an arc *c e* on the valve stem. Next turn the driver ahead until the valve is just cutting off on the other end. With the same center *a* as used before, describe another arc *f g* on the valve stem. These two arcs are known as the *port lines* and are to be the reference lines for the work which follows. Draw a straight horizontal line *H I* on the valve stem and where it intersects the arcs, make the center marks *A B*. The center *A* is the front port mark and the center *B* the back port mark. Next, place the reverse lever in the extreme backward position and locate points on the valve stem similar to the points *A* and *B*.

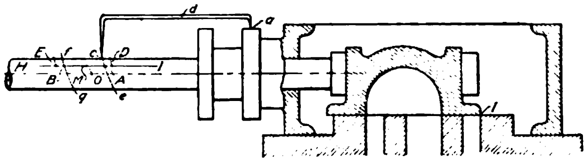
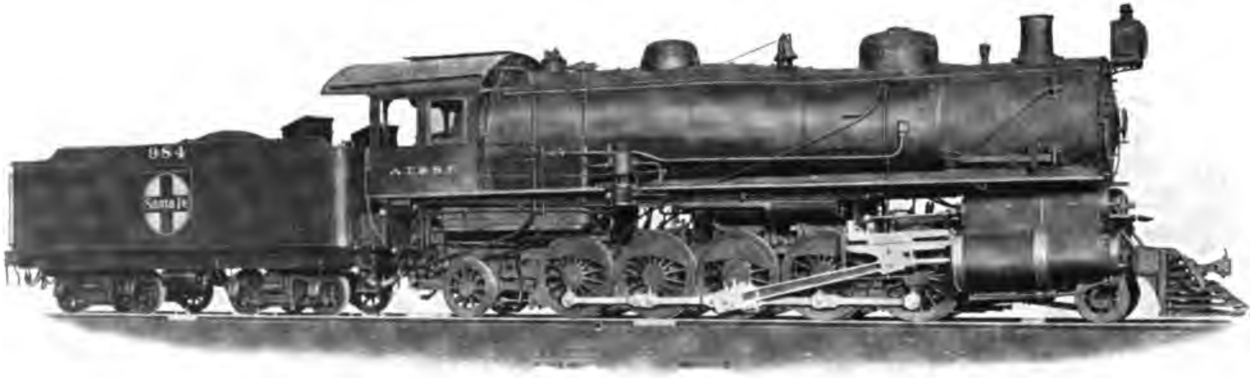


Fig. 67. Illustration of Method of Setting Locomotive Valves.

To avoid confusion, it is better to make all tram marks for the forward movement above the line *H I* and all those for the backward motion below.

In trying the forward movement of the valve, see that the reverse lever is in the extreme forward position, then by running the engine ahead, place the crank in turn on each dead center, and describe an arc on the valve stem. In trying the valve for the backward gear, place the reverse lever in its extreme back position and by running the engine backward, place the crank on each dead center and describe arcs on the valve stem as before. In either case, if the dead center is past, do not back up to it but either make another revolution



COMPOUND SANTA FE TYPE LOCOMOTIVE, FOR HEAVY FREIGHT SERVICE,
BUILT FOR ATCHISON, TOPEKA & SANTA FE RAILWAY COMPANY.
Baldwin Locomotive Works.

of the engine or back beyond it some distance, then approach it from the proper direction. This must be done in order to eliminate all lost motion.

These trial tram lines should be compared with the port marks when the engine is placed in the forward and backward gear.

If the trial tram lines fall outside of the port marks, so much lead is indicated, while if they fall within the port marks, so much negative lead is indicated.

It is customary for railroad companies to set the valves on their locomotives to give equal lead. The method commonly employed is presented herewith. Having the reverse lever in the extreme forward notch, run the engine ahead, stopping it on the forward dead center. With the tram *b* in the center *a*, Fig. 67, describe the arc *D* above the line *H I*. Next turn the engine ahead until the back dead center is reached; using the tram *b* again with a center at *a*, describe the arc *E* above the line *H I*. With dividers, find a mid-point *O* between *E* and *D*. If the center *O* is ahead of the point *M*, which is midway between the port marks *A* and *B*, the eccentric blades which control the forward motion must be shortened an amount equal to the distance between *M* and *O*. When this is done, the lead will be equalized. If it is desired to increase the lead, move the forward eccentric toward the crank. To decrease the lead, move the forward eccentric away from the crank. After all of these changes have been made, repeat the operation in order to check the results. If this does not give the desired results, correct the error by repeating the process and continue by trial until the conditions sought for are obtained.

To set the valves for the back motion, proceed in the same manner as that described for the forward motion, all the changes being made on the eccentric blades and eccentric which control the backward motion.

In all that has been said regarding the setting of the Stephenson valve gear, it is assumed that the gear is one having *open rods;* that is, one in which the rods are open, not crossed when the eccentrics face the link.

WALSCHAERT VALVE GEAR. The Walschaert valve gear is illustrated by the line diagram in Fig. 68. Fig. 69 shows its application to a Consolidation freight locomotive. From a study of Fig. 68, it is obvious that the motion of the valve is obtained from the crosshead and an eccentric crank attached to the main crank pin. In some designs, the eccentric crank is replaced by the usual form of eccentric attached to the main driving axle. The crosshead connection imparts a movement to the valve which in amount equals the lap plus the lead when the crosshead is at the extremities of the stroke, in which position the eccentric crank is in its mid-position. The lead of the valve is constant and can only be changed by altering the leverage relation of the combination lever. The eccentric crank actuates the eccentric rod which, in turn, moves the link to and fro very much the same as does the eccentric blade in the Stephenson gear. There is a radius bar, Fig. 68, which connects the link block with the valve stem. It is evident, therefore, that the valve obtains a motion from the eccentric crank, link, radius bar, and valve rod in a manner very similar to the Stephenson gear, the essential difference being in the crosshead connection which results in giving the valve a constant lead.

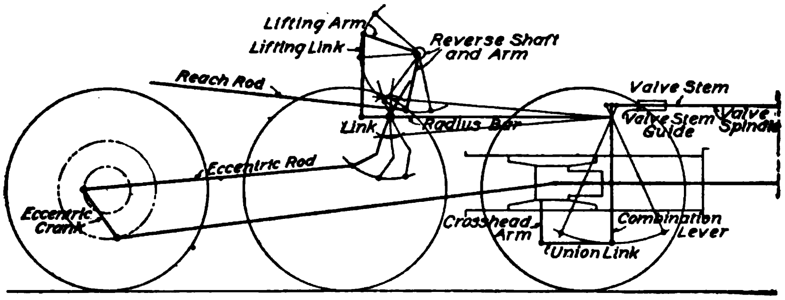


Fig. 68. Diagram of Walschaert Valve Gear.

It is to be noted that in a valve having internal admission, the radius bar connects with a combination lever above the valve rod connection, as shown in Fig. 69, and that in a valve having external admission, the connection is made below the valve rod, as illustrated in Fig. 68; also, in a valve having internal admission, the eccentric crank follows the main crank, while in a case where the valve has external admission, it precedes the main crank. Theoretically, the eccentric crank is placed 90 degrees from the main crank but because of the angularity of the eccentric rod, it is usually two or three degrees more than this.

The Walschaert gear is operated by a reverse lever in the same manner as the Stephenson gear. In the Stephenson gear, a movement of the reverse lever causes the link to be raised or lowered, the link block remaining stationary, whereas in the Walschaert gear, the link remains stationary and the link block is raised or lowered. From a study of the two gears, it may be stated that the chief point of difference is that the Walschaert gives a constant lead for all cut-offs, whereas the Stephenson gives a different lead for different cut-offs.

The following steps given by the American Locomotive Company for adjusting the Walschaert valve gear are presented:

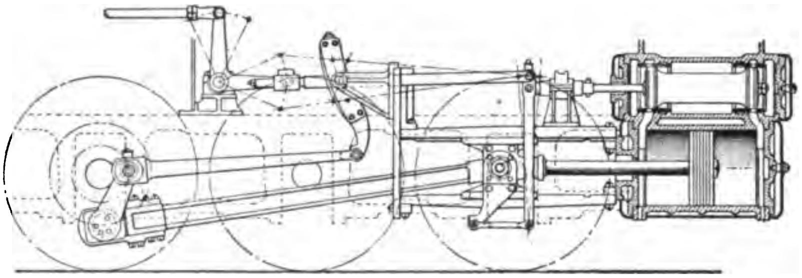


Fig. 69. Walschaert Gearing Mounted on a Consolidation Locomotive.

1. The motion must be adjusted with the crank on the dead centers by lengthening or shortening the eccentric rod until the link takes such a position as to impart no motion to the valve when the link block is moved from its extreme forward to its extreme backward position. Before these changes in the eccentric are resorted to, the length of the valve stem should be examined as it may be of advantage to plane off or line under the foot of the link support which might correct the length of both rods, or at least only one of these should need to be changed.
2. The difference between the two positions of the valve on the forward and back centers is the lead and lap doubled and it cannot be changed except by changing the leverage relations of the combination lever.
3. A given lead determines the lap or a given lap determines the lead, and it must be divided for both ends as desired by lengthening or shortening the valve spindle.
4. Within certain limits, this adjustment may be made by shortening or lengthening the radius bar but it is desirable to keep the length of this bar equal to the radius of the link in order to meet the requirements of the first condition.
5. The lead may be increased by reducing the lap, and the cut-off point will then be slightly advanced. Increasing the lap introduces the opposite effect on the cut-off. With good judgment, these qualities may be varied to offset other irregularities inherent in transforming rotary into lineal motion.

6. Slight variations may be made in the cut-off points as covered by the preceding paragraph but an independent adjustment cannot be made except by shifting the location of the suspension point which is preferably determined by a model.

A comparison of the Stephenson and Walschaert valve gears shows that steam distribution in the former would not differ to a very great extent from that in the latter save in that produced by the constant lead. The factors in favor of the Walschaert gear are largely mechanical ones which may be designated as *easily accessible parts* and a *less amount of care in maintenance.* The parts making up the Walschaert valve gear are outside of the frames where they can be easily reached in case of break downs and necessary repairs. Another advantage accruing from this fact is that the space between the frames is left open permitting bracing, which protects and strengthens the frames. This is not possible when the Stephenson gear is used. The smaller number of moving parts, hardened pins, and accessible bearings in the Walschaert gear result in fewer and less expensive repairs.

Valves. The valve ordinarily used on locomotives is the *plain slide valve* which is also partially balanced. In the plain slide valve the full steam chest pressure is exerted over the whole of the back surface of the valve. The balancing of a valve consists in removing a portion of this pressure, thus decreasing the frictional resistance of the valve on its seat. The percentage of this pressure that is removed, or the *amount of balance,* varies from 45 to 90 per cent of the total face of the valve, and the average in practice is about 65 per cent. In the valve shown in Fig. 70, the balance is 69 per cent. The pinch of the packing ring on the cone slightly increases the pressure of the valve on its seat.

In Fig. 70, the valve, 1, is of the ordinary *D* type driven by the yoke, 2, which is forged as a part of the valve stem. To the back of the valve is bolted a circular plate, 3, having a cone turned thereon. On this cone is fitted a loose ring, 4, the inner face of which is beveled to the same degree as the taper of the cone. The ring is cut at one point and is, therefore, flexible. The open space at the cut in the ring is covered by an L-shaped clip which is placed on the outside and fastened to one end of the ring, the other end of the ring remaining free. This L-shaped clip reaches to the top of the ring at the outside and under the ring at the bottom to the taper of the cone. It thus forms joints just the same as the ring itself, making a continuous yet flexible ring. The ring is made of cast iron and is bored smaller than the diameter required for the working position. Therefore, before the steam chest cover is placed in position, it sets slightly higher on the cone than it does when at work. To the inner side of the steam chest cover, 6, is bolted a back plate, 5, against which the ring, 4, forms a steam tight joint. Owing to the raised position of the ring when first put on, the placing of the cover and the back plate forces the ring down over the cone. This expands the former to a larger diameter and it is thus held in its expanded position under tension with the tendency to maintain the joint between itself and the wearing plate.

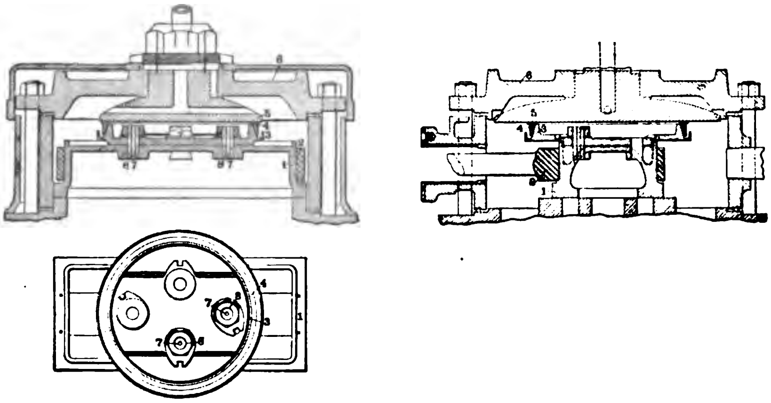


Fig. 70. Plain Slide Valve.

Another method employed in balancing a slide valve is to cut grooves in the top of the valve which extend across the four sides of the valve. In these grooves are placed carefully fitted narrow strips which rest on small springs which keep the strips pressed up against a pressure plate, thus keeping the steam away from a large part of the valve.

In order to provide for any leakage which may occur past the ring and to prevent an accumulation of pressure within the same, the holes, 7, are drilled through the studs, 8. These drain the space and accomplish the desired result.

A relief valve is placed on the steam chest. This is a check valve opening inward and serves to equalize the pressure in the two ends of the cylinder when the locomotive is coasting, thus preventing unequal pressure at either end.

Another form of valve which is now being extensively used is the *piston valve,* illustrated in Fig. 71. In this valve, the steam is admitted at the center in the space *A* and is exhausted at the ends. Such valves are self-balanced since they are entirely surrounded by steam. Another form of piston valve is constructed with a passage extending through its entire length which connects with a live steam passage. In this type of valve, steam is admitted at the ends of the valve at *B*, and when exhausted passes around the circular part *A* to the exhaust cavity. In piston valves, it only remains to pack the ends to prevent steam leaks. This is done by using packing rings. In Fig. 71, the packing consists of seven pieces at each end, numbered 1, 2, 3, and 4. Numbers 3 and 4 are the packing rings proper. They consist of the split rings, 3, and the L-shaped covering piece, 4, for the split in No. 3. The rings, 2, are solid and serve merely as surfaces against which the rings, 3, have a bearing. The wedge ring, 1, is split and can expand. The rings, 3, are turned larger than the diameter of the steam chest and are sprung into position. Small holes, 5, are drilled from the steam space *A* to a point beneath the wedge ring, 1. When the throttle valve is opened, steam enters the holes, 5, by forcing the wedge, 1, out between the rings, 2. It locks the packing ring, 3, firmly between the ring, 2, and the lip of the valve. This prevents all rattling and working loose of the rings. The valve is then practically a steam-tight plugged valve.

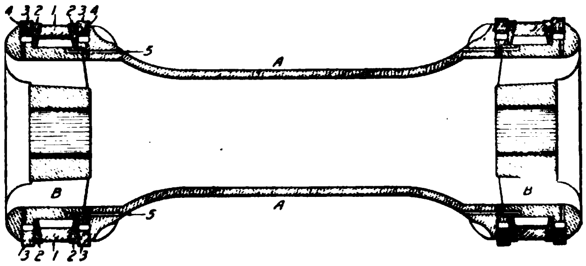


Fig. 71. Piston Valve.

A form of packing largely used and which is much simpler than the above, consists of ordinary snap rings inserted into annular grooves cut around the heads of the valves. These snap rings press against the walls of the valve cylinder and form a steam-tight joint.

Running Gear. The running gear of a locomotive is composed of the following important parts: Wheels, axles, rods, pistons, and the frames which form a connection between these parts.

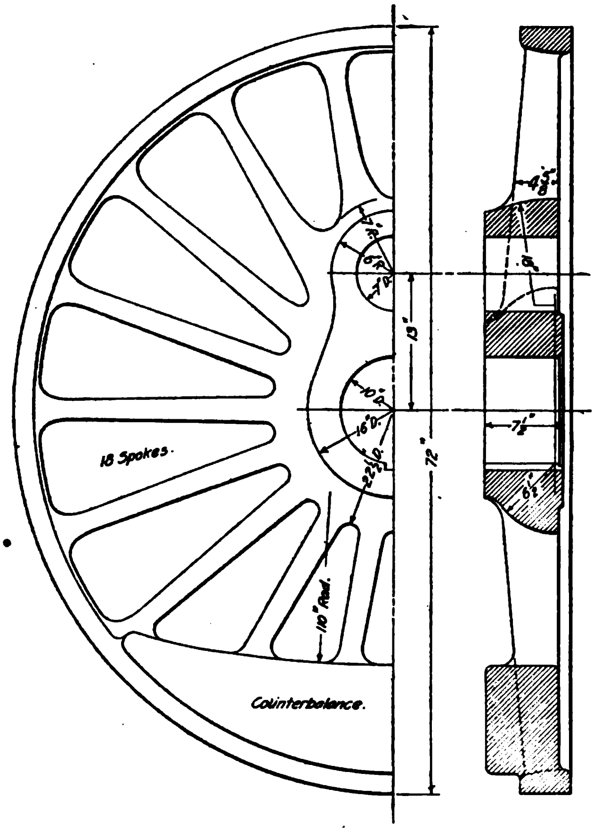


Fig. 72. Half-Elevation and Section of Driving Wheel.

The *driving wheels* are made with a cast-iron or steel center protected by a steel tire. Until about 1896, cast iron was universally employed for wheel centers and is yet used for the smaller engines. For engines having large cylinders where a saving of weight is important, cast steel is now used. Such a wheel is illustrated in Fig. 72. The universal method of fastening the tire to the center is to bore it out a trifle smaller than the diameter to which the center is turned, then expand it by heating and after slipping it over the center allow it to contract by cooling. The shrinkage commonly used is $\frac{1}{80}$ of an inch for each foot diameter of wheel center for all centers of cast iron or cast steel less than 66 inches in diameter. For centers more than 66 inches in diameter, $\frac{1}{80}$ of an inch for each foot diameter is allowed for shrinkage. This gives the following shrinkages:

TABLE IV

Shrinkage Allowance

Diameter of Center	Shrinkage	Bored Diameter of Tire
56	.058	55.94
58	.060	57.94
60	.063	59.93

The American Master Mechanics' Association recommends the following concerning wheel centers:

In order to properly support the rim and to resist the tire shrinking, the spokes should be placed from 12 to 13 inches apart from center to center, measured on the outer circumference of the wheel center. The number of spokes should equal the diameter of center expressed in inches divided by 4. If the remainder is $\frac{1}{2}$ or over, one additional spoke should be used. The exact spacing of the spokes according to this rule would be

$$3.1416 \times 4 = 12.56 \text{ inches}$$

Wheel centers arranged in this manner would have the following number of spokes:

TABLE V

Spoke Data—General

Diameter of Centers	Number of Spokes	Diameter of Centers	Number of Spokes
38	10	72	18
44	11	74	19
50	13	76	19
56	14	78	19
62	16	80	20
66	17		

Among pattern makers and foundry men, there is an impression that an uneven number of spokes should be used so as to avoid getting two spokes directly opposite each other in a straight line. The following table has been made up on this basis:

TABLE VI

Spoke Data—Foundry Rule

Diameter of Center	Number of Spokes	Pitch	Diameter of Center	Number of Spokes	Pitch
44	11	12.5	66	15	13.8
48	11	13.6	68	17	12.5
50	13	12.6	70	17	12.9
54	13	13.0	72	17	13.3
56	13	13.5	74	17	13.6
60	15	12.6	76	19	12.6
62	15	13.0	78	19	12.9

The spokes at the crank hub should be located so that the hub will lie between two of the spokes and thus avoid a short spoke directly in line with the crank pin hub.

Cast steel driving wheel centers should be preferably cast with the rims and uncut shrunk slots omitted whenever steel foundries will guarantee satisfactory castings. For wheel centers 60 inches in diameter and when the total weight of the engine will permit, the rims should preferably be cast solid without cores so as to obtain the maximum section and have full bearing surface for the tires.

It is difficult to get sufficient counterbalance in centers smaller than 60 inches in diameter so that it will be found very desirable to core out the rims to obtain the maximum lightness on the side next to the crank pin and in some cases on the counterbalance side in order to fill in with lead where necessary.

The American Master Mechanics' Association recommends a rim section as shown in Fig. 73 for wheel centers without retaining rings. The tire is secured from having the center forced through it by a lip on the outside ⅜ inch in width and about ⅛ inch in height, the tire being left rough at this point. The height of the lip, therefore, depends upon the amount of finishing left on the interior of the tire. Accurate measurements of tires after they have been in service for some time, especially when less than 2½ inches in thickness, show that a rolling out or stretching of the tire occurs, and for reasonably heavy centers, these figures will account more for loose tires than any permanent set in the driving wheel center.

Counterbalance. A study of the construction of the driving wheel brings up the question of counterbalance since it is made a part of the wheel center. The counterbalance, Fig. 72, is the weight or mass of metal placed in the driving wheel opposite the crank to balance the revolving and reciprocating weights.

The revolving weights to be balanced are the crank pin complete, the back end of the main rod or connecting rod, and each end of each side rod complete. The sum of the weights so found which are attached to each crank pin is the revolving weight for that pin.

The reciprocating weights to be balanced consist of the weight of the piston complete with packing rings, piston rod, crosshead complete, and the front end of the main rod complete. The weight of the rod should be obtained by weighing in a horizontal position after having been placed on centers.

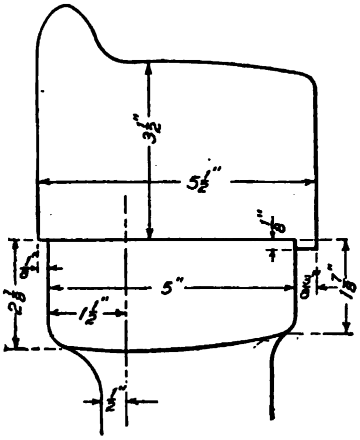


Fig. 73. Section of Rim of Driving Wheel.

The revolving weights can be counterbalanced by weights attached to the wheel to which they belong, while the reciprocating weights can only be balanced in one direction by adding weights to the driving wheels as all weights added after the revolving parts are balanced overbalance the wheel vertically exactly to the same extent that they tend to balance the reciprocating parts horizontally. This overbalance exerts a sudden pressure or hammer blow upon the rail directly proportional to its weight and to the square of its velocity. At high speeds, this pressure, which is added to the weight of the driver on the rail, may become great enough to injure the track and bridges.

The best form of counterbalance is that of a crescent shape which has its center of gravity the farthest distance possible from the center of the axle. The counterbalance should be placed opposite the crank pin as close to the rods as proper clearance will allow. The clearance should be not less than ¾ inch. No deficiency of weight in any wheel should be transferred to another. All counterbalance blocks should be cast solid. When it is impossible to obtain a correct balance for solid blocks, they may be cored out and filled with lead, which will increase their weight. In all such cases the cavities must be as smooth as possible. Holes should be drilled through the inside face of the wheel to facilitate the removal of the core sand.

In counterbalancing a locomotive, the following fundamental principles should be kept in mind:

1. The weight of the reciprocating parts, which is left unbalanced, should be as great as possible, consistent with a good riding and smooth working engine.
2. The unbalanced weight of the reciprocating parts of all engines for similar service should be proportional to the total weight of the engine in working order.
3. The total pressure of the wheel upon the rail at maximum speed when the counterbalance is down, should not exceed an amount dependent upon the construction of bridges, weight of rail, etc.
4. When the counterbalance is on the upper part of the wheel, the centrifugal force should never be sufficient to lift the wheel from the rail.

The following rules have been generally accepted for the counterbalancing of locomotive drive wheels:

1. Divide the total weight of the engine by 400, subtract the quotient from the weight of the reciprocating parts on one side including the front end of the main rod.
2. Distribute the remainder equally among all driving wheels on one side, adding to it the sum of the weights of the revolving parts for each wheel on that side. The sum for each wheel if placed at a distance from the driving wheel center, equal to the length of the crank, or at a proportionately less weight if at a greater distance, will be the counterbalance weight required.

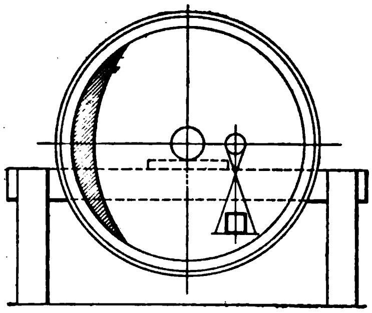


Fig. 74. Diagram Showing Method of Counterbalancing Driving Wheels.

The method of adjusting the counterbalance in the shop is as follows: After the wheels have been mounted on the axle and the crank pins put in place, the wheels are placed upon trestles as illustrated in Fig. 74. These trestles are provided with perfectly level straight edges upon which the journals rest. A weight pan is suspended from the crank pin as shown. In this pan is placed weight enough to just balance the wheels in such a position that a horizontal line will pass through the center of the axle and crank pin and counterbalance on one wheel, and a vertical line will pass through the axle and crank pin centers of the other side, the crank being above. The amount of weight thus applied, including the pan and the wire by which it is suspended, gives the equivalent counterbalance at crank radius available for balancing the parts. This weight found must not exceed that found to be necessary by the formula. Should the counterbalance be left with extra thickness, the extra weight can be turned off with little trouble after the trial described has been completed. This process should be repeated for the opposite side.

The weight of the reciprocating parts should be kept as low as possible, consistent with good design. Locomotives with rods disconnected and removed should not be handled in trains running at high rates of speed because of the danger arising from damage to the track and bridges, due to the hammer blow.

Axles. Driving and engine truck axles are made of open hearth steel, having a tensile strength not less than 80,000 pounds per square inch. Modern practice requires that axles conform to the tests and standards adopted by the American Railway Master Mechanics' Association and the American Society for Testing Materials. One axle is required to be tested from each heat. The test piece may be taken from the end of any axle with a hollow drill, the hole made by the drill to be not more than 2 inches in diameter nor more than 4½ inches deep. This test piece is to be subjected to the physical and chemical tests provided for in the code of the societies mentioned above.

All forgings must be free from seams, pipes, and other defects, and must conform to the drawings furnished by the company. The forgings, when specified, must be weighed, turned with a flat nosed tool, and cut to exact length and centered with 60 degree centers. All forgings not meeting the above requirements or which are found to be defective in machining and which cannot stand the physical chemical tests will be rejected at the expense of the manufacturers.

The above requirements, while intended for driving axles, apply in a general way to engine truck axles. Axles are forged from steel billets, of the proper size to conform to the size of the axles as required for standard gauge work.

In accordance with the foregoing, Table VII is presented, which gives the sizes and the weights of billets for standard driving and engine truck axles.

TABLE VII

Forged Steel Billets (Standard Sizes)

DRIVING AXLES			ENGINE TRUCK AXLES		
Diameter of Journal, Inches	Size of Billet, Inches	Weight of Billet, Pounds	Diameter of Journal, Inches	Size of Billet, Inches	Weight of Billet, Pounds
8	10 x 10	2590	5	7 x 7	970
8½	11 x 11	2900	5½	7 x 7	1170
9	11 x 11	3220	6	8 x 8	1380
9½	12 x 12	3570	6½	8 x 8	1600
10	12 x 12	3930	7	9 x 9	1830

After the axles are received in the rough state, the journals and wheel fits are turned up, in the shop, to the proper dimensions. In turning up the wheel fits, they are left slightly larger in diameter than the diameter of the axle opening in the wheel center. The wheel center is then forced on the axle by means of hydraulic pressure. Table VIII gives the pressure employed in forcing-in engine truck and driving axles.

TABLE VIII

Hydraulic Pressures Used in Mounting Axles

DRIVING AXLES			ENGINE TRUCK AXLES		
Diameter of Fit in Inches	Pressure Employed in Tons		Diameter of Fit in Inches	Pressure Employed in Tons	
	Cast-Iron Center	Cast-Steel Center		Cast-Iron Center	Cast-Steel Center
7 -7½	70-75	112-120	4 -4½	25-30	37-45
7½-8	75-80	120-128	4½-5	30-35	45-52
8 -8½	80-85	128-136	5 -5½	35-40	52-60
8½-9	85-90	136-144	5½-6	40-45	60-67
9 -9½	90-95	144-152	6 -6½	45-50	67-75
9½-10	95-100	152-160	6½-7	50-55	75-82
10 -10½	100-105	160-168	7 -7½	55-60	82-90
10½-11	105-110	168-176			

Crank-pins. All specifications and test requirements mentioned under the discussion of driving and engine truck axles are applicable to crank-pins. Crank-pins are received by railroad companies in the rough forging and must, therefore, be turned to fit the wheel boss. They are forced in by hydraulic pressure, the pressures commonly employed being given in Table IX.

TABLE IX

Hydraulic Pressures Used in Mounting Crank-Pins

Diameter of Fit in Inches	Pressure Employed in Tons	
	Cast-Iron Center	Cast-Steel Center
3-3½	15-20	24-32
3½-4	20-25	32-40
4-4½	25-30	40-48
4½-5	30-35	48-56
5-5½	35-40	56-64
5½-6	40-45	64-72
6-6½	45-50	72-80
6½-7	50-55	80-88

Locomotive Frames. Among other details of importance in the construction of a locomotive, none is more important than the frame. The frame is the supporting element and the tie bar that connects all the various moving and fixed parts. Its present form and proportions are due most largely to development rather than to pure design. It would be extremely difficult to analyze all the various forces to which the frames are subjected. There are two principal classes of locomotive frames, namely, the *single front rail* and the *double front rail.* The single front rail is illustrated in Fig. 75. At first the joint between the main frame and the front rail was made as shown at *A* in Fig. 75. The rear end of the front rail was bent downward with a

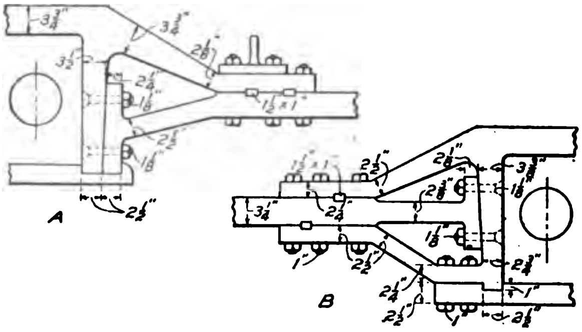


Fig. 75. Single Front Rail Locomotive Frames.

T-foot formed thereon by means of which it was connected to the main frame. The top member of the main frame was bent down and extended forward and connected to the front rail by means of bolts and keys. The T-head was fastened to the pedestal by two countersunk bolts. As locomotives grew in size, much trouble was experienced due to the countersunk bolts becoming loose or breaking. To overcome this difficulty, the form of joint shown in *B*, Fig. 75, was developed. Here the pedestal had a member welded to it which extended forward and upward to meet the front rail. The top member extended outward and downward as before. The front rail fitted between these two members and had a foot which rested against the pedestal. This latter form was used for many years, being changed in details considerably but retaining the same general arrangement. These forms of single bar frames continued to be used for many years and are employed at the present time for light locomotives. When the heavier types of locomotives, such as the Consolidation, made their advent, it became necessary to improve the design of the frame. To meet this necessity, the double front rail frame was developed. Fig. 76 illustrates one of the earlier forms of this frame. The top rail was placed upon and securely bolted to the top bar of the main frame and the lower front rail was fastened to the pedestal by means of a T-foot with countersunk bolts. The same difficulty was experienced with this design as with the first form

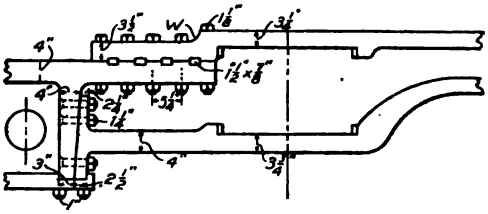


Fig. 76. Early Form of Double Front Rail Frame.

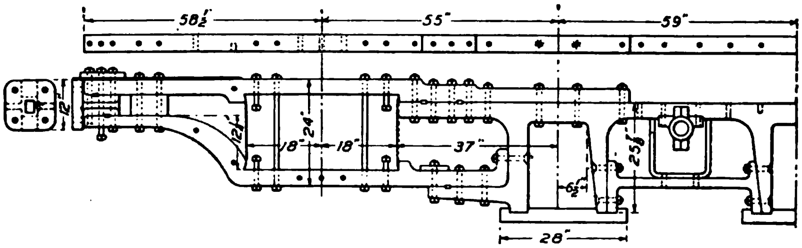


Fig. 77. Heavy Form of Double Front Rail Frame.

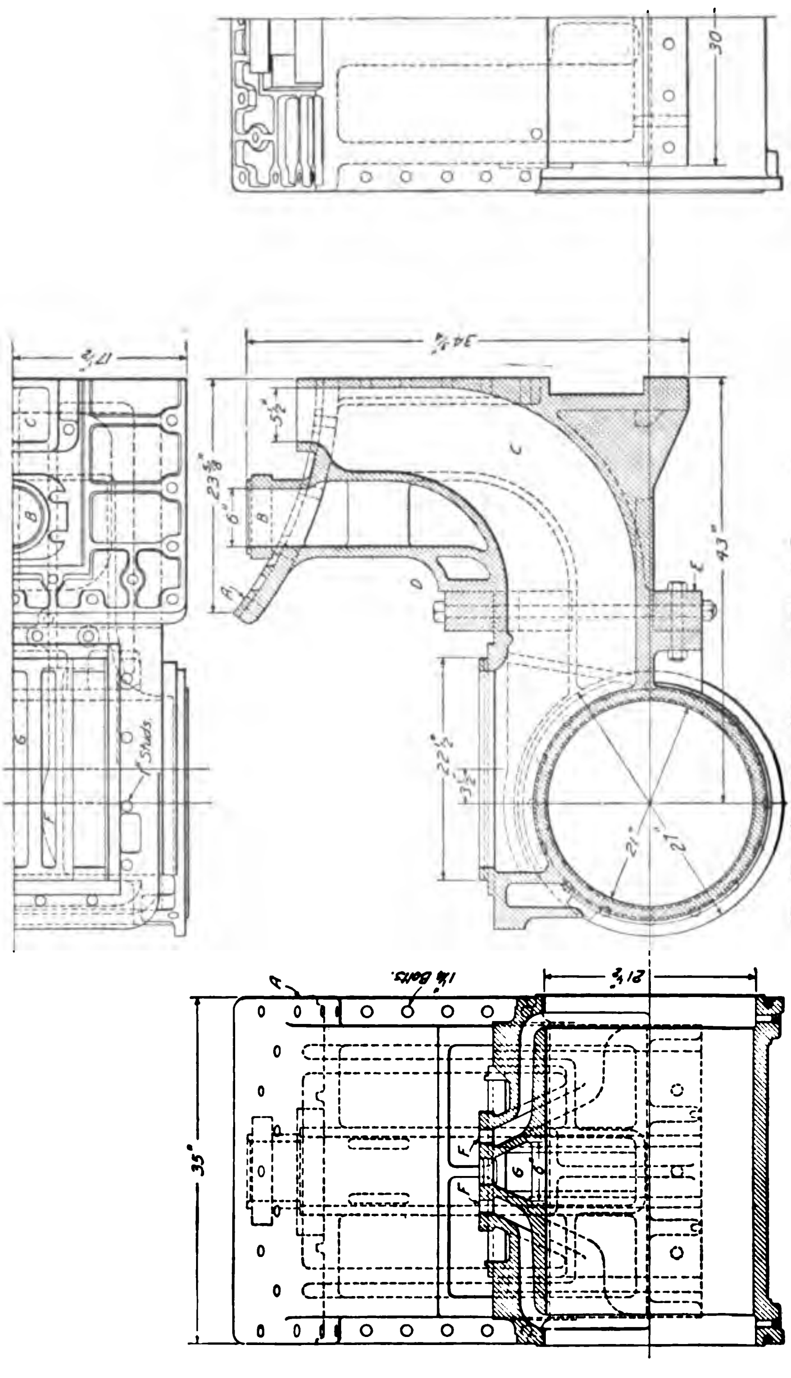
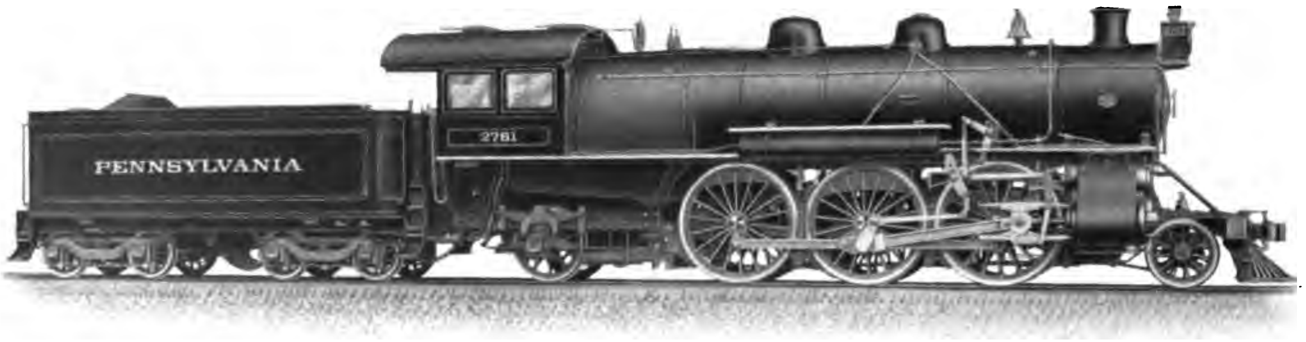


Fig. 78. Cylinder and Saddle of Simple Locomotive.



PRAIRIE TYPE OF LOCOMOTIVE, BUILT FOR THE PENNSYLVANIA RAILROAD
American Locomotive Co.

of the single front rail type, namely, the breaking of the bolts fastening the lower bar to the pedestal. This led to experiments being tried which resulted in many stages of advancement until a heavy and serviceable design was developed, as shown in Fig. 77. In this design the pedestal has a bar welded to it on which the lower front rail rests and to which it is connected by means of bolts and keys. The top front rail rests on top of the top main frame and extends back beyond the pedestal, thus giving room for the use of more bolts. The design shown in Fig. 77 is the one largely used on all heavy locomotives, it being slightly changed in detail for the various types.

In addition to the two general types of bar locomotive frames which are made of wrought iron or mild steel, a number of cast-steel frames are being used. The general make-up of the cast-steel frame does not differ materially from that of the wrought iron except in the cross-section of the bars. The bar frame is rectangular or square in cross-section whereas the sections of cast-steel frames are usually made in the form of an I.

Cylinder and Saddle. The cylinder and saddle for a simple locomotive, illustrated in Fig. 78, are constructed of a good quality of cast iron. The casting is usually made in two equal parts but it is not uncommon to find the saddle formed of one casting, each cylinder being bolted to it, making three castings in all. Fig. 78 illustrates the two-piece casting commonly used. The two castings are interchangeable and are securely fastened together by bolts of about 1¼ inches in diameter. The part of the casting known as the *saddle* is the curved portion *A*, which fits the curved surface of the smoke-box of the boiler. This curved surface after being carefully chipped and fitted to the smoke-box is then securely fastened to it by means of bolts. This connection must not only be made very securely but air tight as well, in order that the vacuum in the smoke-box may be maintained. In the cross-sectional view, the live steam passage *B* and exhaust passage *C* are shown. The steam enters the passage *B* from the branch pipe and travels to the steam chest from which it is admitted into the cylinder through the steam ports *F*. After having completed its work in the cylinder, it passes through the exhaust port *G* into the exhaust passage *C* to the stack. The cylinder casting is fastened to the frames of the locomotive as well as to the boiler. *D* and *E* show the connection of the saddle casting to the frame. In this case a frame having a double front rail is used, each bar being securely bolted to the casting.

The Piston and Rods. The pistons of locomotives vary greatly in details of construction but the general idea is the same in all cases. Since the pistons receive all the power the locomotive delivers, they must be strongly constructed and steam tight. All pistons consist of a metal disk mounted on a piston rod which has grooves on the outer edges for properly holding the packing rings. The pistons are commonly made of cast iron, but where great strength is required, steel is now being used. Fig. 79 illustrates the present tendency in design. The cylindrical plate is made of cast-steel and the packing rings, two in number, are made of cast iron. The packing rings are of the snap ring type and are free to move in the grooves.

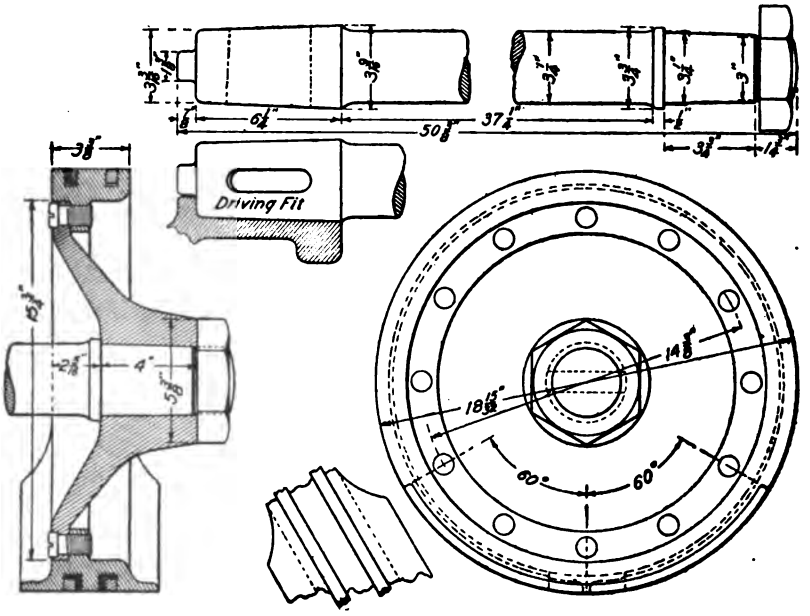


Fig. 79. Piston and Rods of Modern Locomotives.

As can be seen, the rim is widened near the bottom in order to provide a greater wearing surface. Fig. 79 also clearly shows the method used in fastening the piston to the piston rod. The piston rod is made of steel and has a tapered end which fits into the crosshead where it is secured by a tapered key. The crosshead fit is made accurate by careful grinding. The crosshead key should likewise be carefully fitted.

Crossheads and Guides. A variety of forms of crossheads and guides are now found in use on locomotives, two of the most common of which are illustrated in Fig. 80 and Fig. 81. The form illustrated in Fig. 80 is known as the *4-bar guide* and that shown in Fig. 81, as the *2-bar guide.* The form used depends largely on the type of engine. The 4-bar guide now used on light engines consists of four bars *A* which form the guide with the crosshead *B* between them. The bars are usually made of steel and the crosshead of cast-steel having babbitted wearing surfaces. The 4-bars *A* are bolted to the guide blocks *C* and *D* which are held by the back cylinder head and the guide yoke *E*, respectively. The guide yoke *E* is made of steel, extends from one side of the locomotive to the other, is securely bolted to both frames, and serves to hold the rear end of both guides. There is usually a very strong brace connected to the guide yoke

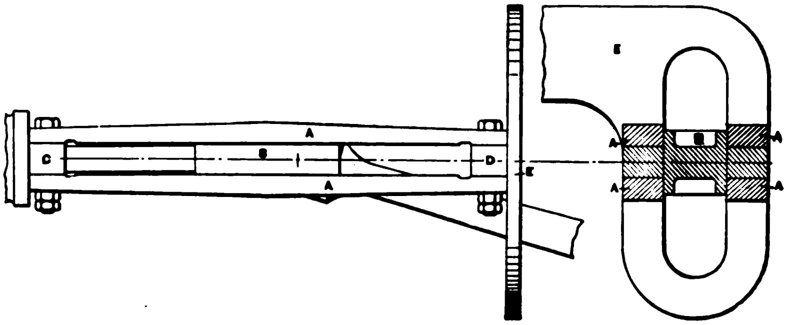


Fig. 80. Common Form of Crosshead and Guides.

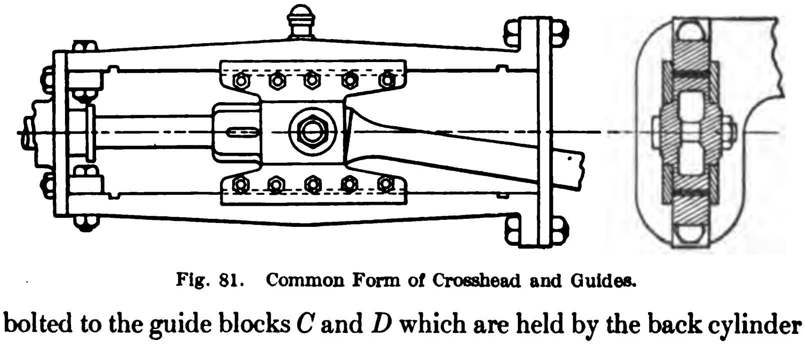


Fig. 81. Common Form of Crosshead and Guides.

which is riveted to the boiler. The wrist pin used in the crosshead of the 4-bar type is cast solid with the crosshead.

The 2-bar guide consists of two bars, one above and one below the center line of the cylinder with the crosshead between them. In this type the parts are more accessible for making adjustments and repairs and the wrist pin is made separate from the crosshead.

In the design of the crosshead, the wearing surface must be made large enough to prevent heating. In practice it has been found that for passenger locomotives the maximum pressure between the crosshead and guides should be about 40 pounds per square inch while

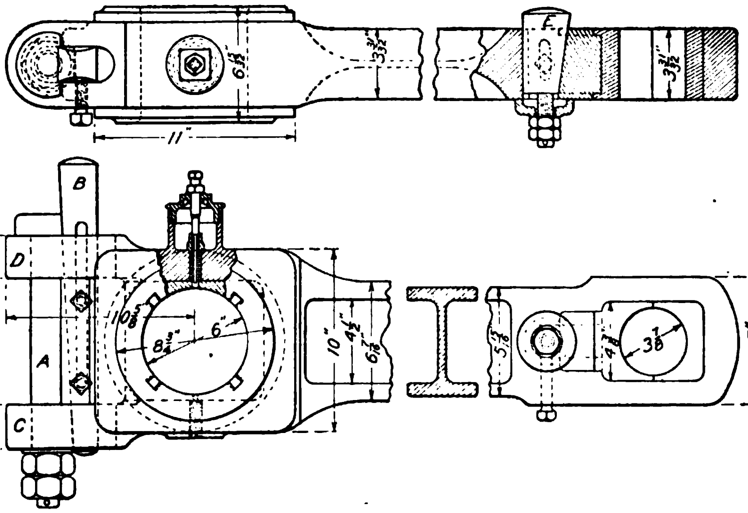


Fig. 82. Connecting Rod Details.

for freight locomotives it may be as high as 50 pounds per square inch. For crosshead pins, the allowable pressure per square inch of projected area is usually assumed at 4,800 pounds, the load on the pin to be considered as follows: For simple engines, the total pressure on the pin is taken to be equal to the area of the piston in square inches multiplied by the boiler pressure in pounds per square inch; for compound engines of the tandem and Vauclain types, the total pressure on the pin is taken to be equal to the area of the low-pressure piston in square inches multiplied by the boiler pressure in pounds per square inch, the whole being divided by the cylinder ratio plus 1. In the latter case, the cylinder ratio equals the area of the high-pressure cylinder divided by that of the low-pressure cylinder.

Connecting or Main Rods. Connecting or main rods are made of steel, the section of which is that of an I. The I-section gives the greatest strength with a minimum weight of metal. Fig. 82 illustrates modern practice in the design of connecting rods for a heavy locomotive. The design for passenger locomotives is quite similar to that shown. Aside from the general dimensions and weight of the rod, there are to be noted some important details in the manner in which the brasses are held and the means provided for adjusting them. The older forms of rods had a stub end at the crank pin end with a strap bolted to the rod. A key was used in adjusting the brasses. With the building of locomotives of greater capacity, this construction was found to be weak. The connecting rod shown in Fig. 82 has passed through several stages in the process of its development. The crank end is slotted, the brasses being fitted between the upper and lower jaw. The brasses are held in place by a heavy cotter *A* and a key *B*. The cotter is made in a form which prevents the spread of the jaws *C* and *D*. The adjustment of the brasses is made by means of the key *B* in the usual way. The brasses at the crosshead end are adjusted by the wedge *E*. The oil cups are forged solidly on the rod.

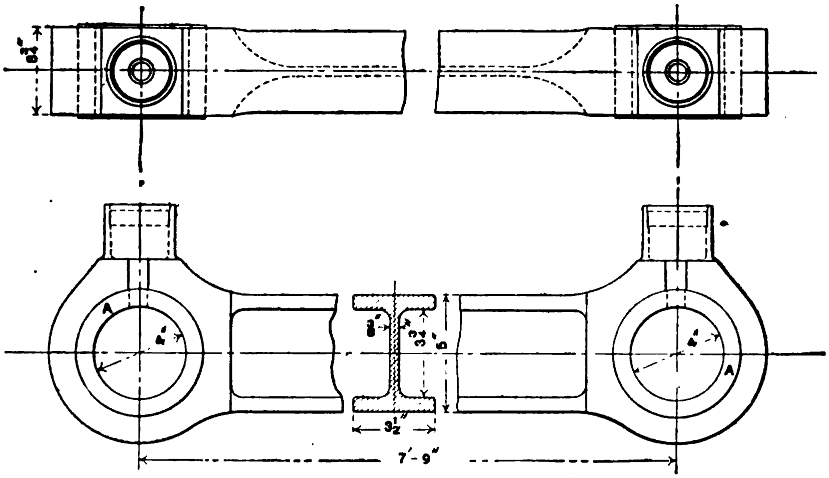


Fig. 83. Side Rod.

The Parallel or Side Rods. The parallel or side rods are also made with an I-section in order to obtain a maximum strength with a minimum weight of metal. Fig. 83 illustrates the form of side rods now being used. The rods are forged out of steel, in the same manner as connecting rods, having oil cups also forged on. The enlarged ends are bored for the brasses which are made solid and forced in by hydraulic pressure. In case the locomotive is one having more than two pairs of drivers, the side rods are connected by means of a hinged joint as shown at *A*, Fig. 84.

Both connecting rods and side rods are subjected to very severe stresses. They must be capable of transmitting tensional, compressional, and bending stresses. These stresses are brought about by the thrust and pull on the piston and by centrifugal force.

Locomotive Trucks. The trucks commonly used under the front end of locomotives are of two types, namely, the *two-wheeled* or *pony truck* and the *four-wheeled truck*

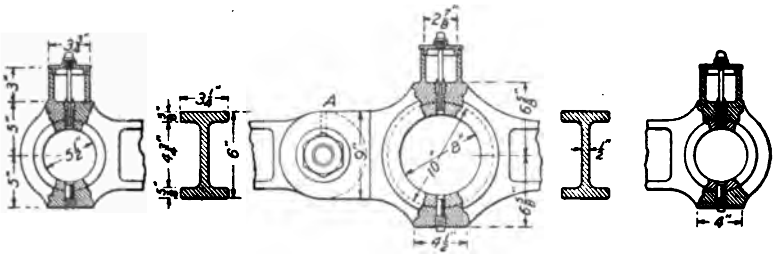


Fig. 84. Hinged Joint for Use with Locomotives Having More Than Two Pairs of Drivers.

The pony truck, illustrated in Fig. 85, consists essentially of the two wheels and axle, the frame, 1, which carries the weight of the front end of the locomotive and the radius bar, 2, pivoted to the cross bar, 3, which is rigidly bolted to the engine frame, 4. The radius bars serve to steady the truck and reduce the flange wear on the wheels when running on curves. A side movement is provided for at the center plate, which is made necessary on account of curves. The correct length of the radius bar is given by the following formula:

$$X = \frac{D\,R + D^2}{R + 2\,D}$$

where

R = length of rigid wheel base of engine in feet

D = distance in feet from front flanged driver axle to center of truck

X = length in feet of radius bar

The usual method of applying the weight to a pony truck is by means of the equalizing lever, 5. The fulcrum, 6, of this equalizing lever is located under the cylinders where the weight is applied. The front end of the equalizing lever is carried by the pin, 8, which, in turn, is carried by the sleeve, 9, and transmits the load to the center plate while the rear end of the lever is supported by means of the cross lever, 10, which is carried by the driving wheel springs.

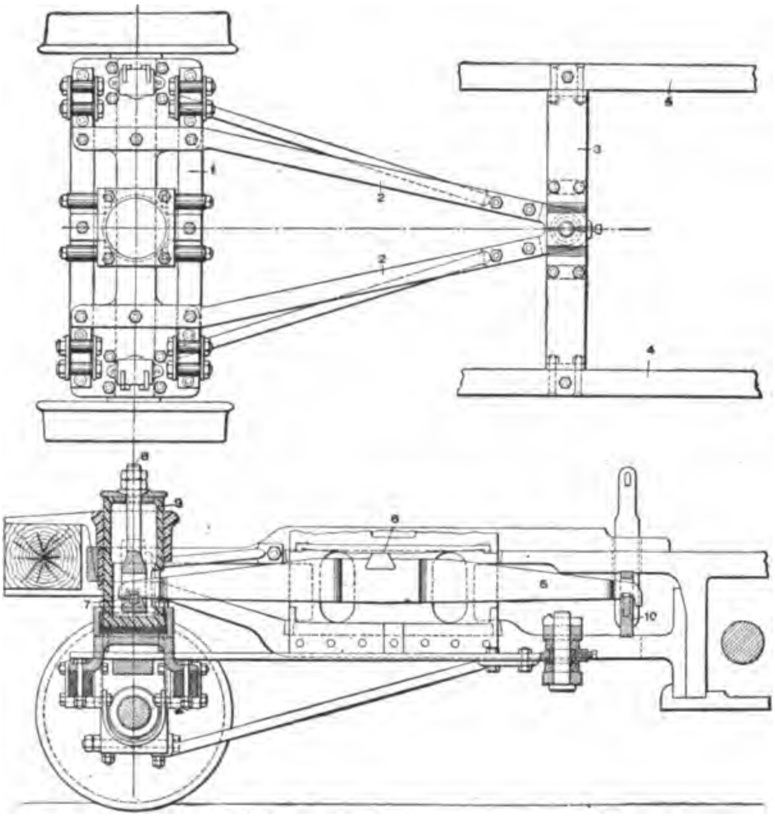


Fig. 85. Pony or Two-Wheeled Truck.

The four-wheeled truck is constructed in a number of different ways, one of which is illustrated in Fig. 86. The construction is simple, consisting of a rectangular frame, *A*, carrying a center plate, *B*. As in the case of the pony truck, the journals are inside of the wheels.

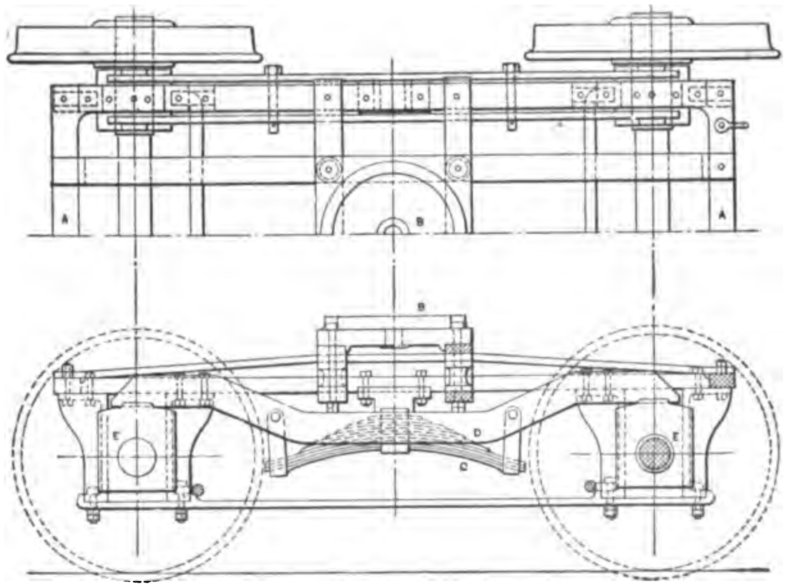


Fig. 86. Four-Wheeled Truck.

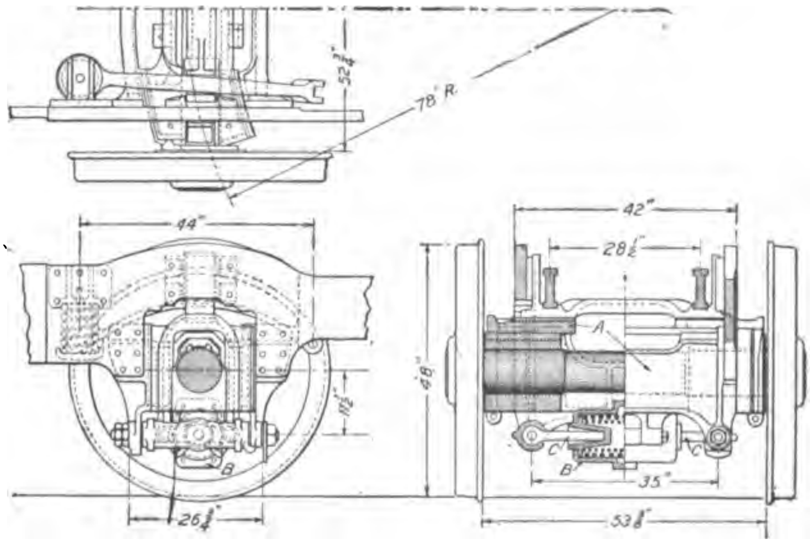


Fig. 87. Trailing Truck with Inside Bearings.

The truck, which is pivoted on the center plate, carries the front-end of the locomotive and serves as a guide for the other wheels of the locomotive.

The object in using a trailing truck, as stated earlier in this work, is to make possible the wide fire box which is necessary in certain types of locomotives. Two different types of trailing trucks are used and both have proven successful. One has an inside bearing, as illustrated in Fig. 87, and the other an outside bearing, as shown in Fig. 88. The former is perhaps the simpler of the two. The latter has a broad supporting base which improves the riding qualities of the locomotive.

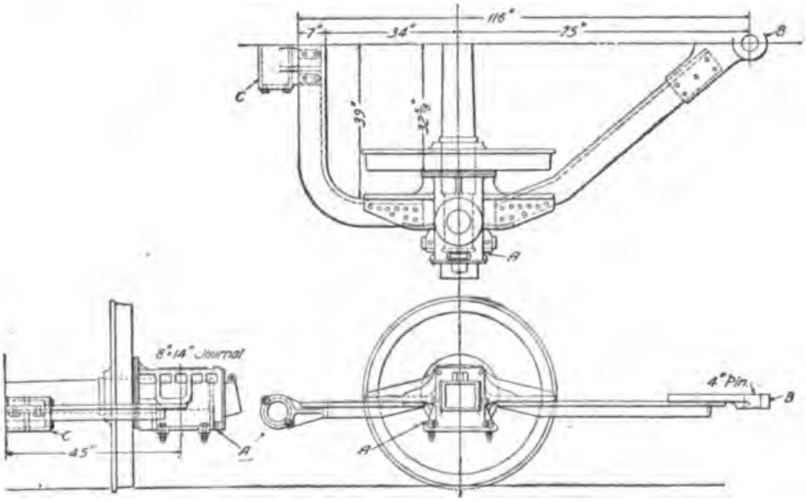


Fig. 88. Trailing Truck with Outside Bearings.

The radial trailing truck with inside bearings, Fig. 87, is fitted with a continuous axle box, *A*, with journal bearings at each end, these being provided at the frame pedestals with front and back wearing surfaces formed to arcs of concentric circles of suitable radii. To the lower face of the continuous axle box is attached a spring housing, *B*, fitted with transverse coiled springs having followers and fitted with horizontal thrust rods, *C*, which extend to the pedestal tie bars. These thrust bars terminate in ball and socket connections at each end. This combination of springs and thrust rods permits the truck to travel in a circular path and also permits the continuous axle box to rise and fall relatively to the frames. Motion along the circular arcs is limited by stops at the central spring casing, the springs tending to bring the truck to its normal central position when the locomotive passes upon a tangent from a curve. The load is transmitted to the continuous axle box through cradles on which the springs and equalizers bear, hardened steel sliding plates being interposed as wearing surfaces immediately over the journal bearings. The cradles are guided vertically by guides attached to the locomotive frames.

The radial trailing truck with outside bearings, as illustrated in Fig. 88, has journal boxes *A* rigidly attached to the frame, the forward rails of which converge to a point in which the pivot pin *B* is centered. The pin is fixed in a cross brace secured between the engine frames. The trailing truck frame extends back of the journal boxes in the form of the letter *U* at the center of which a spring housing *C* is mounted, containing centering springs and followers, performing the same functions as those of the radial truck with inside bearings, already described. The load in this case is transmitted to the journal boxes by springs which are vertically guided. Hardened rollers are generally used between what would otherwise be sliding surfaces. These rollers rest upon double inclined planes which tend to draw the truck to its normal and central position when displaced laterally as on a curve. The mutual action of these rollers and inclined planes is to furnish a yielding resistance to lateral displacement with a tendency to return to the normal position.

The Tender. The tender of a locomotive is used to carry the coal and water supply for the boiler. It is carried on two four-wheeled trucks having a frame work of wood or steel, the latter being mostly used at the present time. This frame supports the tank in which the water is stored, which, in the case of passenger and freight locomotives, is usually constructed in the shape of the letter U, the open end of which faces the fire door. The open space between the legs of the U is used for coal storage. The water is drawn from the tank near the two front corners. In these two front corners are placed tank valves which are connected by means of the tank hose and pipes to the two injectors. Near the back end of the tank is a manhole which permits a man to enter the inside to make repairs. This opening is also used in filling the tank at water towers. Tanks are made of open hearth steel, usually about $\frac{1}{4}$ of an inch in thickness, the sheets being carefully riveted together to prevent leaks. The interior of the tank is well braced and contains baffle plates which prevent the water from surging back and forth, due to curves and shocks in the train itself. The tank is firmly bolted to the frame.

The capacity of tenders has been increased as the locomotives which they serve have grown in size and power. Modern heavy locomotive tenders have a water capacity of from 3,000 to 9,000 gallons and a coal capacity of from 5 to 16 tons.

On switching engines, the back end of the tank is frequently made sloping in order to permit the engineer to see the track near the engine when running backward. Frequently a tool box is placed near the rear of the tank in which may be kept jacks, replacers, etc. A tool box for small tools and signals is usually placed at the front of the tender on either side. The coal is prevented from falling out at the front end by using gates or boards dropped into a suitably constructed groove. On locomotives used on northern railroads, the tanks are provided with a coil of steam pipes by means of which the water can be warmed and prevented from freezing.

DESIGN OF PARTS OF THE ENGINE

The design of the parts of the locomotive engine proper, like that of the boiler, is a subject which cannot be handled properly in the space allotted in this book. A few formulae, for the most part based on rational assumptions, are presented for the calculation of some of the most important parts.

Axles. The stress in the axles is combined in many ways. The principal stresses are, first, bending stresses due to the steam pressure on the piston; second, bending stresses due to the dead weight of the engine; third, torsional or shearing stresses due to unequal adhesion of the wheels on the rails; and fourth, bending stresses due to the action of the flanges on the rails while rounding curves. Let

W = the area of the piston in square inches multiplied by the boiler pressure in pounds per square inch

L_1 = the lever arm in inches or the distance from the center of the main or connecting rod to the center line of the frame

O = the lever arm in inches or the distance from the center of the side rod to the center line of the frame

M = bending moment or the load in pounds times the lever arm in inches

d = the diameter of axle in inches

R = the section modulus which for a solid circular section $= .0982\ d^3$

If there are only two pairs of drivers, the force W will be equally distributed between the crank pins as shown in A, Fig. 89.

If the force W, the total steam on the piston, is assumed to act alone, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_1 = \frac{W\,L_1}{2\,R}$$

for the main axle, and

$$S_1 = \frac{W\,O}{2\,R}\,.$$

for the back axle.

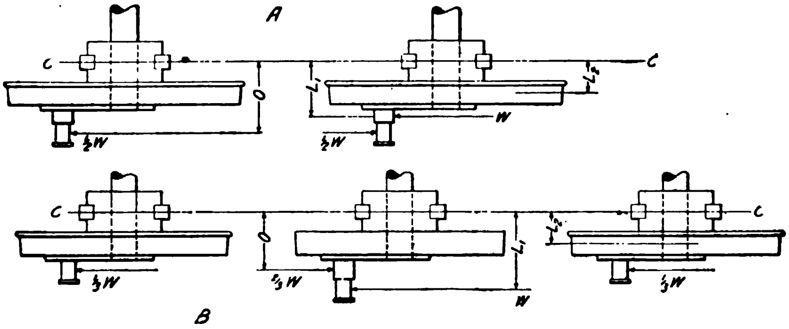


Fig 89. Force Diagram for Drivers.

Let

W_1 = the dead load in pounds on each journal

and

L_2 = lever arm in inches or the distance from the center of the driving box or frame to the center line of the rail.

Then, if the force W_1 be assumed to act alone, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_2 = \frac{W_1\,L_2}{R}$$

Let

L_3 = the crank radius, or one-half the length of the stroke in inches.

If the twisting of the axle alone is considered, the torsional or shearing stress in pounds per square inch produced in the axle will be

$$S_3 = \frac{W\,L_3}{2\,R}$$

Because of certain existing conditions which affect the amount of torsion or twisting of the axle, only one-half of the theoretical stress should be used, as it is not probable that under any circumstances could more be transmitted by the axle to the opposite side.

Let

D = the diameter of drivers in inches

F = the centrifugal force in pounds

W_2 = the weight in pounds of the moving mass of wheels plus the weight carried by them

g = the acceleration of gravity in feet per second = 32.2

r = the radius of curvature of the track in feet

v = the velocity of the locomotive in feet per second

If the action on a curve alone is considered, the maximum fiber stress in pounds per square inch produced in the axle will be

$$S_4 = \frac{F\,D}{2\,R}$$

where

$$F = \frac{W_2\,v^2}{r\,g}$$

Considering all stresses acting together, we get the resultant maximum fiber stress in pounds per square inch in the axle to be

$$S'' = \frac{S'}{2} + \sqrt{\frac{(S')^2}{4} + \frac{(S_3)^2}{2}}$$

where

$$S' = \sqrt{(S_1)^2 + (S_2)^2}$$

In this equation, the bending stress due to the centrifugal force while rounding curves does not appear since it is assumed that this will neutralize that due to the dead load on the axle.

The following allowable fiber stresses in pounds per square inch have been used in successful designs:

TABLE X

Fiber Stresses

TYPE OF LOCOMOTIVE	IRON	STEEL
Consolidation	7,500	8,500
10 wheel or Mogul	8,500	9,500
8 wheel passenger	10,500	13,000

Example. Determine the fiber stresses in the driving axle of an 8-wheel passenger locomotive having the following dimensions: cylinder 20 inches in diameter, length of stroke 26 inches, steam pressure 200 pounds per square inch, and other dimensions as listed:

O = 21.5 inches
R = 65.77 for an axle $8\frac{3}{4}$ inches in diameter
W_1 = 18,000 pounds
L_2 = $7\frac{1}{2}$ inches
L_3 = 13 inches
D = 75 inches
g = 32.2
r = 955 feet
v = 88 feet per second (60 miles per hour)
W_2 = 42,500 pounds

SOLUTION.

$$S_1 = \frac{W\,O}{2\,R} = \frac{62700 \times 21.5}{2 \times 65.77}$$

$$= 10250 \text{ pounds per square inch}$$

$$S_2 = \frac{W_1\,L_2}{R} = \frac{18000 \times 7.5}{65.77}$$

$$= 2050 \text{ pounds per square inch}$$

$$S_3 = \frac{W\,L_3}{2\,R} = \frac{62700 \times 13}{2 \times 65.77}$$

$$= 6200 \text{ pounds per square inch.}$$

As previously stated, this value would probably never exceed one-half this amount, which assumption gives a fiber stress of 3,100 pounds per square inch.

$$F = \frac{W_2 v^2}{r g} = \frac{42500 \times (88)^2}{955 \times 32.2}$$

$$= 10700 \text{ pounds}$$

$$S_4 = \frac{F D}{2 R} = \frac{10700 \times 75}{2 \times 65.77}$$

$$= 6055 \text{ pounds per square inch}$$

The flange pressure would probably not exceed one-third of the total centrifugal force, the remainder being absorbed by the elevation of the outer rail. If this were true, then

$$S_4 = \frac{6055}{3} = 2018 \text{ pounds per square inch}$$

which, as can be seen, just about neutralizes the stress due to the dead weight.

$$S' = \sqrt{(S_1)^2 + (S_2)^2}$$

$$= \sqrt{10250^2 + 2050^2}$$

$$= 10450 \text{ pounds per square inch}$$

Therefore,

$$S'' = \frac{S'}{2} + \sqrt{\frac{(S')^2}{4} + \frac{(S_3)^2}{2}}$$

$$= \frac{10450}{2} + \sqrt{\frac{(10450)^2}{4} + \frac{(3100)^2}{2}}$$

$$= 10990 \text{ pounds per square inch}$$

Therefore, an 8¾ steel axle is large enough for an 8-wheel passenger locomotive since the allowable fiber stress of 13,000 pounds per square inch is not exceeded.

If the locomotive under consideration was one having three pairs of drivers instead of two, the total piston pressure would be distributed as shown in *B*, Fig. 78.

Crank Pins. Crank pins are calculated for strength by the following methods:

In *A*, *B*, and *C*, Fig. 90, is shown the manner in which the forces act on the crank pins of three different types of locomotives.

Let

W = the boiler pressure in pounds per square inch, times area of the piston in square inches

S = the safe fiber stress in pounds per square inch

L = the lever arm in inches or the distance from the face of the wheel to the center of the main rod

M = maximum moment in inch pounds or force in pounds times the lever arm in inches

P_1 = the force in pounds transmitted to the side rod

d = the diameter of crank pin in inches

L_1 = the side rod lever arm in inches or the distance from the face of the wheel center to the center line of the side rod

R = the section modulus of the crank pin which for a circular section = $.0982\ d^3$

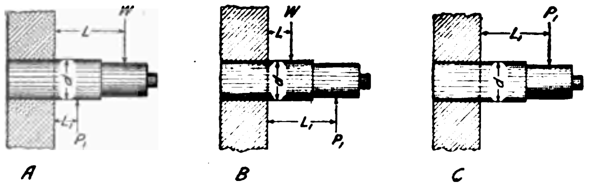


Fig. 90. Action of Force on Crank Pins in Different Types of Locomotives.

Having given the above conditions, we may write

$$M = W\,L - P_1\,L_1$$

and

$$S = \frac{M}{R} = \frac{M}{.0982\ d^3}$$

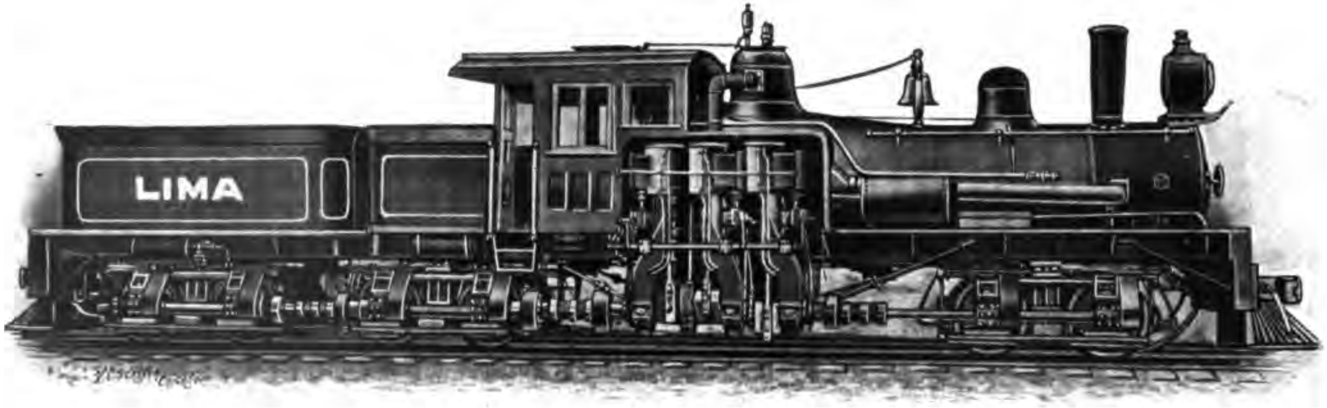
From this last equation

$$d^3 = \frac{M}{.0982\ S}$$

Finally, substituting the value of M we get

$$d = \sqrt[3]{\frac{W\,L - P_1\,L_1}{.0982\ S}}\,.$$

This equation may be used in finding the diameter of the main crank pin on any type of locomotive when the loads and lever arms are known and the safe fiber stress has been assumed. It should be remembered, however, that for an 8-wheeled locomotive it is



SHAY PATENT GEARED LOCOMOTIVE CLASS "C."
Lima Locomotive & Machine Co.

$$P_1 = \frac{W}{2}$$

and for a 10-wheeled locomotive it is

$$P_1 = \frac{W}{3}$$

For crank pins other than main pins on engines having the main rod on the outside, no calculations need be made for bending.

To calculate the back pin, the load is applied as shown in *C*, Fig. 80, and we have

$$M = P_1 L_1$$

and finally

$$d = \sqrt[3]{\frac{P_1 L_1}{.0982 S}}$$

The maximum allowable working stress in pounds per square inch for crank pins is as follows:

TABLE XI

Working Stress for Crank Pins

Class of Locomotives	Steel	Iron
Freight locomotive	15,000	12,000
Passenger locomotive	12,000	10,000

In addition to figuring the crank pins for bending, the bearing surface must be given some attention. In order to prevent overheating and to secure the best results, the pin must be designed so that the unit pressure will not exceed an amount determined by past experience. This allowable pressure in practice varies from 1,600 to 1,700 pounds per square inch of projected area, the projected area being the diameter of the pin multiplied by its length. It often happens that it is necessary to make the pin larger than is required for safe strength in order that the allowable bearing pressure may not be exceeded.

Piston Rods. Because of the peculiar conditions of stress and loading of a piston rod, a very high factor of safety must be used in its design. It is subjected to both tensional and compressional stresses and must be capable of resisting buckling when in compression. Reuleaux gives the following formulae for determining the diameter of piston rods:

Considering tension alone

$$d = .0108\ D \sqrt{P}$$

and considering buckling

$$d = .0295\ D \sqrt{\frac{L}{D}} \sqrt[4]{P}$$

where

D = diameter of cylinder in inches
d = smallest diameter of piston rod in inches
L = length of the piston rod in inches
P = the boiler pressure in pounds per square inch

Example. Given a locomotive having cylinders 20 inches in diameter, piston rod 46 inches long, and carrying a boiler pressure of 190 pounds per square inch. Determine the diameter of the piston rod necessary.

SOLUTION. Considering the problem from the standpoint of tension only, we have

$$\begin{aligned} d &= .0108 \times 20 \sqrt{190} \\ &= 2.98 \text{ inches} \end{aligned}$$

The dimensions of the rod determined from the standpoint of buckling would be

$$\begin{aligned} d &= .0295 \times 20 \sqrt{\frac{46}{20}} \sqrt[4]{190} \\ &= 3.3 \text{ inches} \end{aligned}$$

The size which would probably be used would be, say, 3½ inches, which would allow for wear.

From the above figures, it is evident that if a piston rod is made strong enough to withstand buckling, it will be sufficiently large to resist the tensional stresses which may come upon it.

Frames. As has been previously stated, the frames of a locomotive are very difficult to design because of the many unknown factors which affect the stresses in them. The following method of proportioning wrought-iron and cast-steel frames will give safe values for size of parts although the results thus found will be greater than usually found in practice.

Let

P = the thrust on the piston or the area of the piston in square inches multiplied by the boiler pressure in pounds per inch

A = the area in square inches of the section of the frame at the top of the pedestal

B = the area in square inches of the section of the frame at the rail between the pedestals

C = the area in square inches of the section of the lower frame between the pedestals

Then

$$A = \frac{P}{2600}$$

$$B = \frac{P}{3000}$$

$$C = \frac{P}{4400}$$

Cylinders. The formula commonly used in determining the thickness of boiler shells, circular tanks, and cylinders is

$$t = \frac{p\,d}{2\,f}$$

where

t = thickness of cylinder wall in inches

p = pressure in pounds per square inch

d = diameter of cylinder in inches

f = safe fiber stress which for cast iron is usually taken at 1500 pounds per square inch

For cylinder heads, the following empirical formula may be used in calculating the thickness:

$$T = .00439\,d\,\sqrt{p}$$

where

T = the thickness of the cylinder head in inches

p = boiler pressure in pounds per square inch

d = diameter of stud bolt circle

Cylinder specifications usually call for a close grain metal as hard as can be conveniently worked. The securing of the proper proportions of a cylinder for a locomotive is a matter of great importance in locomotive design. The cylinders must be large enough so that with a maximum steam pressure they can always turn the driving wheels when the locomotive is starting a train. They should not be much greater than this, however, otherwise the pressure on the piston would probably slip the wheels on the rails. The maximum force of the steam in the cylinders should therefore be equal to the adhesion of the wheels to the rails. This may be assumed to be equal to one-fourth of the total weight on the driving wheels. The maximum mean effective piston pressure in pounds per square inch may be taken to be 85 per cent of the boiler pressure.

As the length of the stroke is usually fixed by the convenience of arrangement and the diameter of the driving wheels, a determination of the size of the cylinder usually consists in the calculation of its diameter. In order to make this calculation, the diameter of the driving wheels and the weight on them, the boiler pressure, and the stroke of the piston must be known. With this data, the diameter of the cylinder can be calculated as follows:

The relation between the weight on the drivers and the diameter of the cylinder may be expressed by the following equation:

$$W = \frac{.85\, d^2\, p\, L}{C\, D}$$

where

W = the weight in pounds on drivers
d = diameter of cylinders in inches
p = boiler pressure in pounds per square inch
L = stroke of piston in inches
D = diameter of drivers in inches
C = the numerical coefficient of adhesion

From the above equation, the value of d may be obtained since the coefficient of adhesion C may be taken as .25. The equation then becomes

$$W = \frac{.85\, d^2\, p\, L}{.25\, D}$$

from which

$$d = \sqrt{\frac{.25\ W\ D}{.85\ p\ L}}$$

Example. What will be the diameter of the cylinders for a locomotive having 196,000 pounds on the drivers, a stroke of 24 inches, drivers 63 inches in diameter. and a working steam pressure of 200 pounds per square inch?

SOLUTION.

$$d = \sqrt{\frac{.25 \times 196000 \times 63}{.85 \times 200 \times 24}}$$
$$= 27.5 \text{ inches}$$

The above formula gvies a method of calculating the size of cylinders to be used with a locomotive when the steam pressure, weight on drivers, diameter of drivers, and stroke are known. This formula is based upon the tractive force of a locomotive or the amount of pull which it is capable of exerting.

The *tractive force* of a locomotive may be defined as being the force exerted in turning its wheels and moving itself with or without a load along the rails. It depends upon the steam pressure, the diameter and stroke of the piston, and the ratio of the weight on the drivers to the total weight of the engine, not including the tender. The formula for the tractive force of a simple engine is

$$T = \frac{.85\ p\ d^2\ L}{D}$$

where

T = the tractive force in pounds
d = diameter of cylinders in inches
L = stroke of the piston in inches
D = diameter of the driving wheels in inches
p = boiler pressure in pounds per square inch

When indicator cards are available, the mean effective pressure on the piston in pounds per square inch may be accurately determined and its value p_1 may be used instead of .85 p, in which case the formula becomes

$$T = \frac{p_1\ d^2\ L}{D}$$

Some railroads make a practice of reducing the diameter of the drivers D by 2 inches in order to allow for worn tires.

In the case of a two-cylinder compound locomotive, the formula for tractive force is

$$T = \frac{.85\ p\ (d_1)^2\ L}{1 + \left(\frac{d_1}{d_2}\right)^2 D}$$

where

D = the diameter of the drivers in inches
d_1 = diameter of low-pressure cylinder in inches
d_2 = diameter of high-pressure cylinder in inches

Train Resistance. The resistance offered by a train per ton of weight varies with the speed, the kind of car hauled, the condition of the track, journals and bearings, and atmospheric conditions.

Taking the average condition as found upon American railroads, the train resistance is probably best represented by the Engineering News formula

$$R = \frac{S}{4} + 2$$

in which

R = the resistance in pounds per net ton (2000 pounds) of load
S = speed in miles per hour

The force for starting is, however, about 20 pounds per ton which falls to 5 pounds as soon as a low rate of speed is obtained. The resistance due to grades is expressed by the formula

$$R' = 0.38\,M$$

in which

R' = the resistance in pounds per net ton of load
M = grade in feet per mile

The resistance due to curves is generally taken at from .5 to .7 pounds per ton per degree of curvature. Taking the latter value and assuming that locomotives on account of their long rigid wheel base produce double the resistance of cars, we have

$R'' = .7\ C$ for cars, and
$R'' = 1.4\ C$ for locomotives

in which

R'' = the resistance in pounds per net ton due to curvature
C = the curvature in degrees

Considerable resistance is offered by wind but this is of such a nature that calculations are extremely difficult to make which would be of any practical value.

The resistances mentioned above do not take into account that due to the acceleration of the train. This may be expressed by the formula

$$R''' = .0132\ v^2$$

in which

v = the speed in miles per hour attained in one mile when starting from rest, being uniformly accelerated

R''' = resistance in pounds per net ton due to acceleration

Locomotive Rating. Since the locomotive does its work most economically and efficiently when working to its full capacity, it becomes necessary to determine how much it can handle. The determination of the weight of the train which a locomotive can handle is called the *rating*. This weight will vary for the same locomotive under different conditions. The variation is caused by the difference in grade, curvature, temperature conditions of the rail, and the amount of load in the cars. The variation due to the differences of car resistance arising from a variation of the conditions of the journals and lubrication is neglected because of the assumption of a general average of resistance for the whole.

The usual method of rating locomotives at present is that of tonnage. That is to say, a locomotive is rated to handle a train, weighing a certain number of tons, over a division. This is preferred to a given number of loaded or empty cars because of the indefinite variation in the weights of the loads and the cars themselves.

In the determination of a locomotive rating there are several factors to be considered, namely, the power of the locomotive, adhesion to the rail, resistance of the train including the normal resistance on a level, and that due to grades and curves, value of momentum, effect of empty cars, and the effect of the weather and seasons.

The power of a locomotive and its adhesion to the rails has already been considered. From the formula given, the tractive power can be calculated very closely from data already at hand.

There are three methods in use for obtaining the proper tonnage rating. First, a practical method which consists in trying out each class of engine on each critical or controlling part of the division and continuing the trials until the limit is reached. Second, a more rapid and satisfactory method is to determine the theoretical rating. Third, the most satisfactory method is, first, to determine the theoretical rating and then to check the results by actual trials.

The value of the momentum of a train is a very important element in the determination of the tonnage rating of locomotives on most railroads. In mountainous regions, with long heavy grades, there is little opportunity to take advantage of momentum, while on undulating roads, it may be utilized to the greatest advantage. An approach to a grade at a high velocity when it can be reduced in ascending the same, enables the engine to handle greater loads than would otherwise be possible without such assistance. Hence, stops, crossings, curves, water tanks, etc., will interfere with the make-up of a train if so located as to prevent the use of momentum. It is necessary, therefore, to keep all these points in mind when figuring the rating of a locomotive for handling trains over an undulating division.

The ordinary method of allowing for momentum is to deduct the velocity head from the total ascent and consider the grade easier by that amount.

For example: Suppose that a one per cent grade 5,000 feet long is so situated that trains could approach it at a high speed. The total rise of the grade would be 50 feet but 15 feet of that amount could be overcome by the energy of the train, leaving 35 feet that the train must be raised or lifted by the engine. The grade in which the rise is 35 feet in 5,000 would be a 0.7 per cent grade, so that if the engine could exert sufficient force to overcome the train resistance and that due to a 0.7 per cent grade, the train could be lifted the remainder of the height by its kinetic energy. In this case, the 5,000 feet of one per cent grade could be replaced by a grade of 0.7 per cent 5,000 feet long, and the effect on the load hauled by the engine would be the same if in the latter case the energy of the train were not taken into account. Since the height to which the kinetic energy raises the train is independent of the length of the grade, its effect becomes far less when the grades are long than when short. Thus, for a one per cent grade 1,000 feet long, the total rise being only 10 feet, the kinetic energy would be more than sufficient to raise the weight of the train up the entire grade leaving only the frictional resistance to be overcome by the engine; whereas if the grade were 50,000 feet in length, or a total rise of 500 feet, the energy of the train would only reduce this rise about 15 feet, leaving a rise of 485 feet or the equivalent of a 0.99 per cent grade to be overcome by the engine, a reduction not worth considering.

It is thus seen that the length of a grade exerts a great influence on the value of the momentum.

Within ordinary limits, the following formula gives very accurate results

$$= \frac{d^2 L p_1}{D\left(R' + \frac{a}{2.64}\right)\left(1 - \frac{V^2 - v^2}{.00566\, a\, l \left(1 + \frac{2.64\, R'}{a}\right)}\right)}$$

where

T = number of tons including engine, which can be hauled over a grade with velocities of V and v

d = diameter of cylinder in inches

L = length of stroke in inches

p_1 = mean effective pressure in pounds per square inch

D = diameter of driver in inches.

R' = resistance in pounds per ton on a level track due to friction, air curves, and velocity, which may be taken at 8 pounds per ton

a = grade in feet per mile

l = length of grade in feet

V = velocity in miles per hour at foot of grade

v = velocity in miles per hour at top of grade

Thus, with an engine having cylinders 17 inches in diameter, a stroke of 24 inches, driving wheels 62 inches in diameter, and running at a velocity of 30 miles per hour, the formula gave a rating of 738 tons. On actual tests, it was possible to handle 734 tons with a speed of 10 miles an hour at the top of the grade.

The effect of empty cars is to reduce the total tonnage of the train below what could be handled if they were all loaded. The resistance of empty cars when on a straight and level track varies from 30 to 50 per cent more per ton of weight than loaded cars.

In using the formula given above, loaded cars are assumed. For empty cars, 40 per cent should be added. That is to say, if a train is composed of empty and loaded cars and is found to have a certain resistance, 40 per cent should be added to the portion of resistance due to the empty cars.

There is considerable difference of opinion regarding the allowance which should be made for the conditions of weather, etc. The following is a fair allowance which has been found to give satisfactory results in practice: Seven per cent reduction for frosty or wet rails; fifteen per cent reduction for from freezing to zero temperature; and twenty per cent reduction for from zero to twenty degrees below.

The use of pushing or helping engines over the most difficult grades of an undulating track will increase the train load and thus reduce the cost of transportation.

LOCOMOTIVE APPLIANCES

In order to enable the engineer to operate and control a locomotive successfully and economically a certain number of fittings on the locomotive are necessary. These fittings consist chiefly of the safety valves, whistle, steam gauge, lubricator, water gauges, blower, throttle valve, injector, air brake, and signal apparatus.

Safety Valves. The universal practice at present is to use at least two safety valves of the pop type upon every locomotive boiler. On small locomotives where clearances will permit, the safety valves are placed in the dome cap. On large locomotives where the available height of the dome is limited, the safety valves are usually placed on a separate turret. When limiting heights will not permit the use of turrets, the safety valves may be screwed directly into the roof of the boiler.

The construction of a good safety valve is such that when it is raised, the area for the escape of steam is sufficient to allow it to escape as rapidly as it is formed, and that as soon as the pressure has fallen a pre-determined amount, it will close.

It should be so designed that it can neither be tampered with nor get out of order. It must act promptly and efficiently and not be affected by the motion of the locomotive. These conditions are all fulfilled in the type of valve shown in section in Fig. 91. In this design, the valve *a* rests on the seat *b b* and is held down by a spindle *c*, the lower end of which rests on the bottom of a hole in the valve *a*. A helical spring *d* rests on a collar on the spindle. The pressure on the spindle is regulated by screwing the collar *e* up or down. The valve seat *b b* may be rounded or straight. Outside of the valve seat there is a projection *f*, beneath which a groove *g* is cut in the casing. When the valve lifts, this groove is filled with steam which presses against that portion of the valve outside of the seat, and, by thus increasing the effective area of the valve, causes it to rise higher and to remain open longer than it otherwise would without this projection. The adjustment of the valve is usually made so that after opening, it will

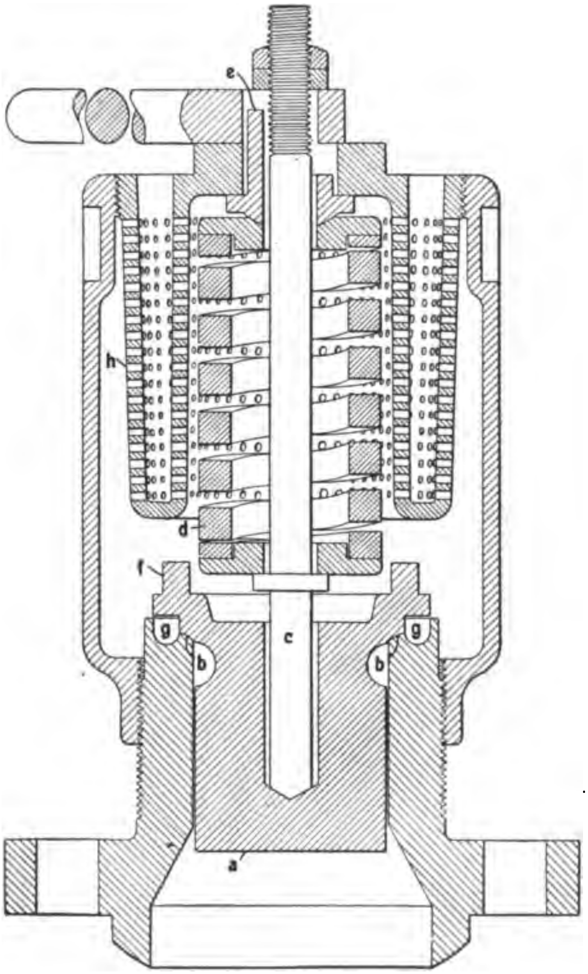


Fig. 91. Section of Safety Valve.

permit steam to escape until the pressure in the boiler is about 4 pounds below the normal pressure. The steam escaping through the small holes *h*, is muffled, thus avoiding great annoyance.

Another form of safety valve which is being largely used is that shown in Fig. 92. The principle of its operation is the same as that just described. It is said to be very quiet and yet gives effective relief. It is being adopted by several railroads.

The Injector. The injector may be defined as an apparatus for forcing water into a steam boiler in which a jet of steam imparts its energy to the water and thus forces it into the boiler against boiler pressure. Injectors are now universally employed for delivering the feed water to the boiler. Two injectors are always used, either one of which should have a capacity sufficient to supply the boiler with water under ordinary working conditions. They are located one on either side of the boiler. Injectors may be classified as *lifting* and *non-lifting*, the former being most commonly used. The lifting injector is placed above the high water line in the tank, therefore in forcing water into the boiler, it lifts the water through a height of a few feet. The non-lifting injector is placed below the bottom of the water tank, hence the water flows to the injector by reason of gravitation.

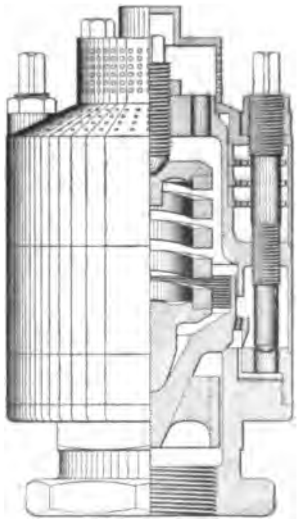


Fig. 92. Another Form of Safety Valve.

There are a great many different injectors on the market. All work upon the same general principle, differing only in the details of construction. One type only will be described, namely, the Sellers injector illustrated in Fig. 93.

Sellers Injector. To operate this injector, the method of procedure is as follows: Draw starting lever, 33, slowly. If the water supply is hot, draw the lever about one inch and after the water is lifted, draw the lever out the entire distance. The cam lever, 34, must be in the position shown. To stop the injector, push the starting

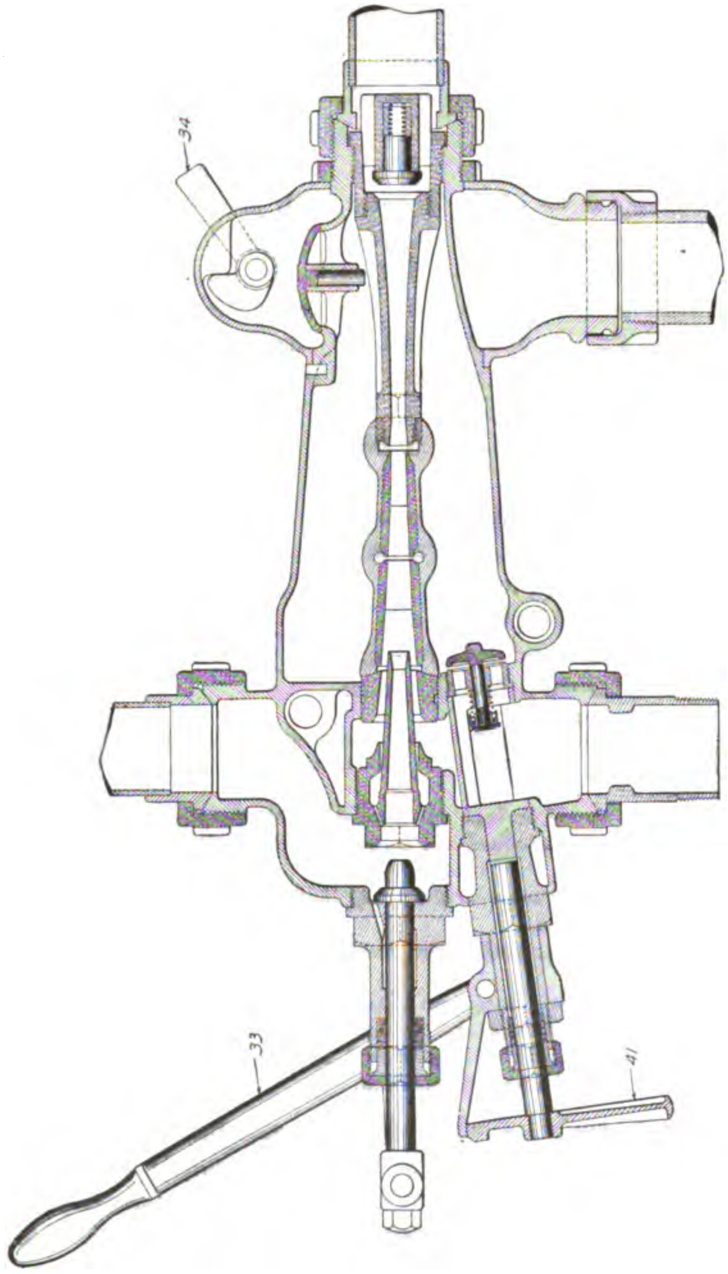


Fig. 93. Sellers Injector.

lever in. To regulate the amount of flow of water after the injector has been started, adjust the regulating handle, 41. If it is desired to use the injector as a heater, place the cam lever, 34, in the rear position and pull the starting lever slowly.

The injector is not a sensitive instrument but requires care to keep it in working condition. It should be securely connected to the boiler in easy reach of the engineer. All joints must be perfectly tight to insure good working conditions. All pipes, hose connections, valves, and strainers must be free from foreign matter. Most failures of injectors are due largely to the presence of dirt, cotton, waste, etc., in the strainers. It is not possible to mention in detail all circumstances which produce injector failures but the complaints commonly heard are as follows:

1. The injector refuses to lift the water promptly, or not at all.

2. The injector lifts the water but refuses to force it into the boiler. It may force a part of the water into the boiler, the remainder being lost in the overflow.

Unless these failures are due to the wearing out of the nozzles which may be renewed at any time, they may be largely avoided by keeping in mind the following points:

All pipes, especially iron ones, should be carefully blown out with steam before the injector is attached, the scale being loosened by tapping the pipes with a hammer.

All valves should be kept tight and all spindles kept tightly packed.

When a pipe is attached to the overflow, it should be the size called for by the manufacturer.

The suction pipe must be absolutely tight since any air leak reduces the capacity of the injector.

The delivery pipe and boiler check valve must be of ample dimensions.

The suction pipes, hose, and tank valve connections must be of ample size and the hose free from sharp kinks and bends.

The strainer should be large enough to give an ample supply of water even if a number of the holes are choked.

The injector is one of the most important boiler appliances, for upon the ability of the injector to promptly supply the necessary water depends the movement of trains. It is, therefore, very necessary to keep the injector in perfect repair by following the hints given above.

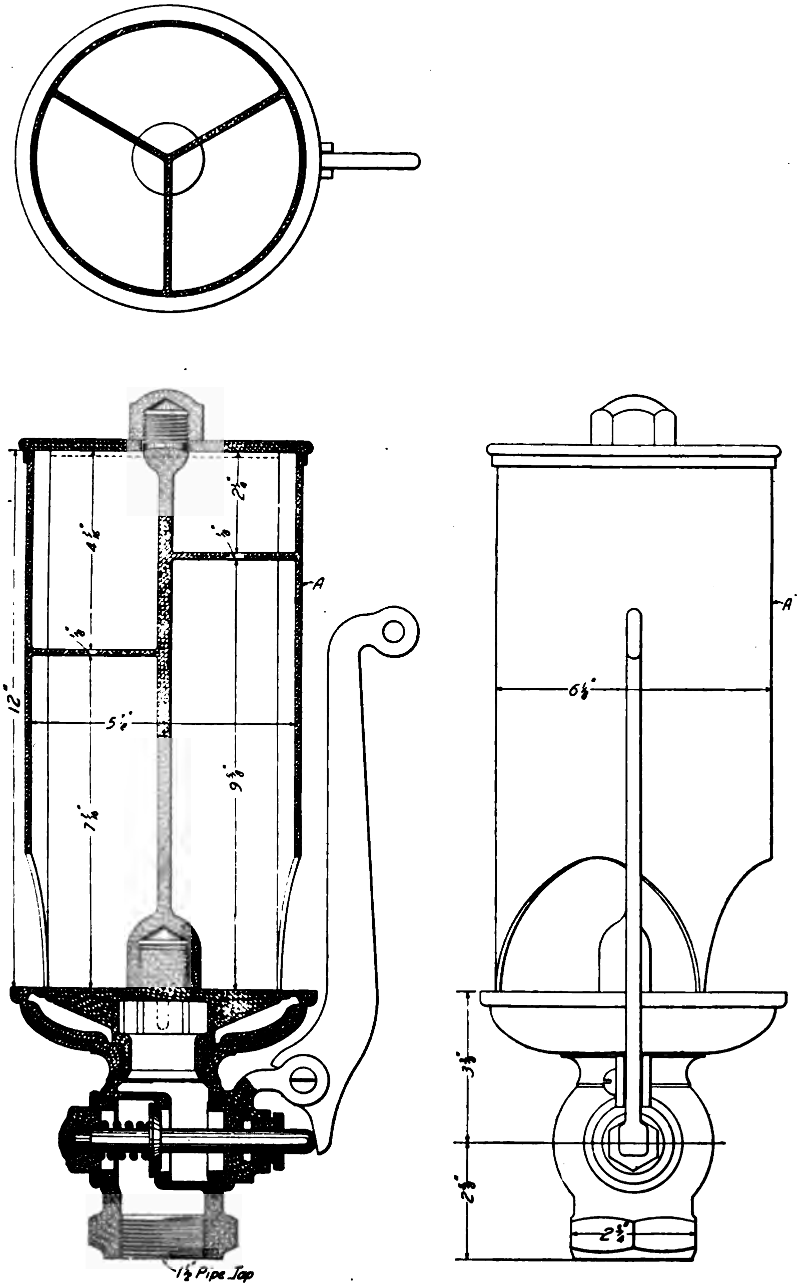


Fig. 94. Locomotive Whistle.

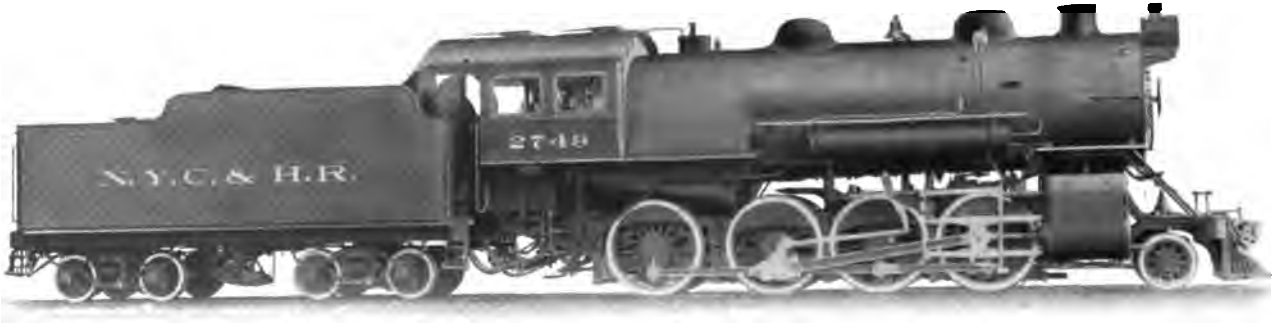
The Whistle. The whistle is used for signaling purposes and consists of a thin circular bell, Fig. 94, closed at the top and sharp at the lower edge. Steam is allowed to escape from a narrow circular orifice directly beneath the edge of the bell. A part of the escaping steam enters the interior of the bell and sets up vibrations therein. The more rapid these vibrations, the higher the tone of the whistle. The tone is affected by the size of the bell and the pressure of the steam. The larger the bell, the lower will be the tone. The higher the steam pressure, the higher the tone. In order to avoid the shrill noise of the common whistle, chime whistles are commonly used, one type of which is illustrated in Fig. 94. In this illustration the bell is divided into three compartments of such proportions that the tones harmonize and give an agreeable chord.

Steam Gauges. The usual construction of the steam gauge will not be presented here but reference is made to the instruction paper on "Boiler Accessories."

Water Gauges. Water gauges are also fully explained in the instruction paper on "Boiler Accessories."

The Blower. The blower consists merely of a steam pipe leading from and fitted with a valve in the cab to the stack where it is turned upward. The end of this pipe is formed into a nozzle. The escaping steam gives motion to the air exactly as already explained for the exhaust and thus induces a draft through the fire-box. It is used when the fire is to be forced while the engine is standing.

Throttle Valve. The throttle valve now in universal use is some form of a double-seated poppet valve, as illustrated in Fig. 95. In this type, two valves *a* and *b* are attached to a single stem, the upper valve being slightly the larger. The lower valve *b* is of such a diameter that it will just pass through the seat of the valve *a*. The steam, therefore, exerts a pressure on the lower face of *b* and the upper face of *a*. As the area of *a* is the greater, the resultant tendency is to hold the valve closed. The valve is, therefore, partially balanced. It will be difficult to open large throttle valves such as are now used on locomotives carrying high steam pressures, with the ordinary direct form of leverage. In such cases, it will be necessary to give a strong, quick jerk to the throttle lever before the valve can be moved from its seat. The arrangement of leverage shown in Fig. 95 obviates this difficulty. The rod *c* connects with a lever in the cab and communi-



CONSOLIDATION TYPE OF FREIGHT LOCOMOTIVE
American Locomotive Co.

cates its movement to the bell crank *d*, whence it is carried by the stem *e* to the valve. The pivot of the bell crank is provided with a slotted hole. At the start, the length of the short arm is about 2¼ inches while the long arm is about 9½ inches. After the valve has been lifted from its seat and is free from excess pressure on *a*, the projecting arm *A* on the back of the bell crank comes in contact with the bracket *B* on the side of the throttle pipe and the bell crank takes the position shown by the dotted lines in the figure. The end of the projecting arm *A* then becomes the pivot and the length of the short arm of the lever is changed to 9½ inches and that of the long arm to about 11½ inches.

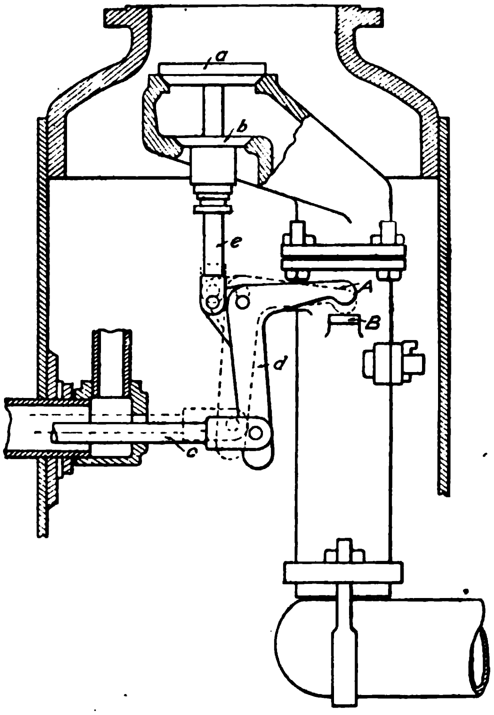


Fig. 95. Throttle Valve.

Dry Pipe. The dry pipe connects with the throttle valve in the steam dome and extends from the dome to the front flue sheet, terminating in the T, which supplies steam to the steam pipes. It is evident, therefore, that the dry pipe must be of such capacity that it will supply both cylinders with a sufficient amount of steam. The following sizes are usually used:

TABLE XII

Dry Pipe Sizes

DIAMETER OF CYLINDER IN INCHES	DIAMETER OF DRY-PIPE IN INCHES
14-17	5
17-19	6
19-21	7
21	8

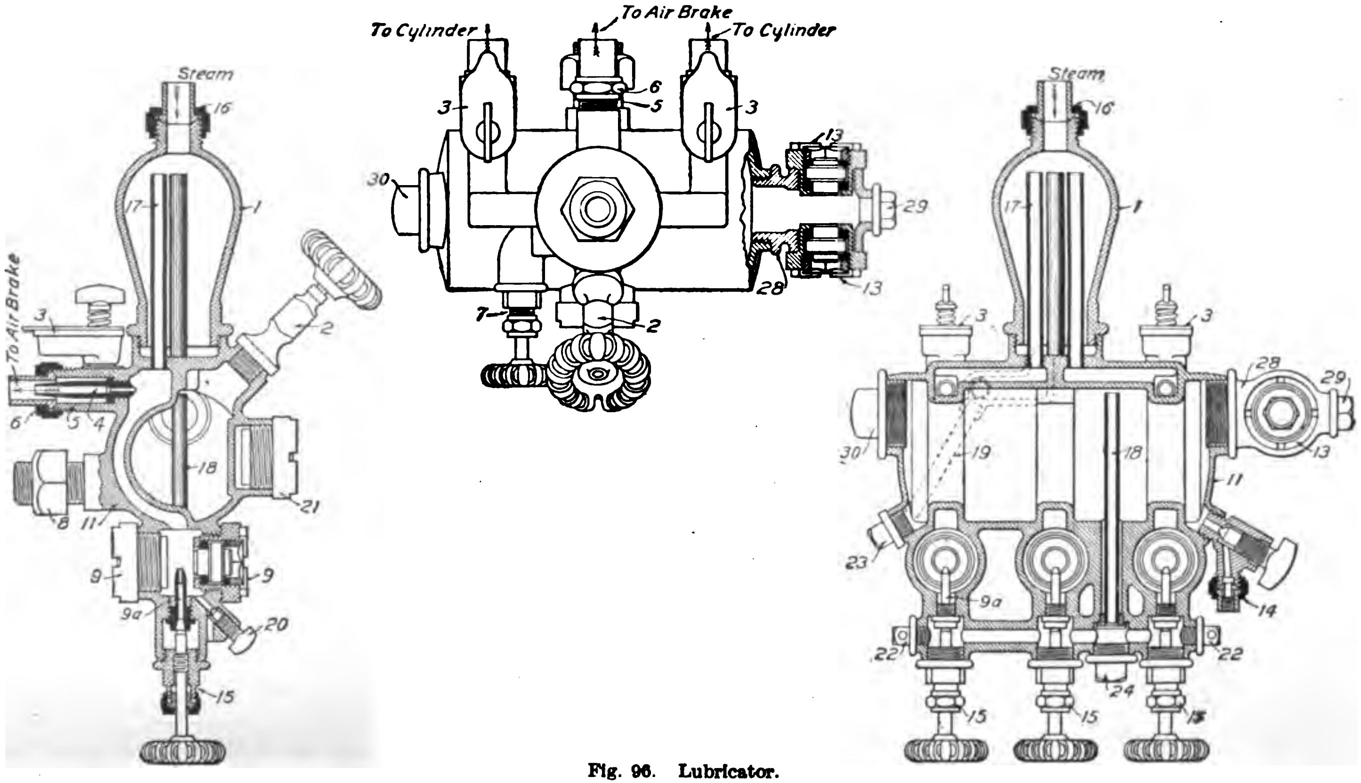


Fig. 96. Lubricator.

Lubricator. The lubricator, one of the most essential locomotive appliances, is usually supported by a bracket from the back head of the boiler in convenient reach of the engineer. It may be a two-, three-, or four-sight feed lubricator as the case demands, the number of sight feeds indicating the number of lubricating pipes supplied by the lubricator. For instance, a two-sight feed lubricator has two pipes leading to each steam chest. A triple sight feed is used to supply oil to both steam chests and also to the cylinder of the air pump. In using super-heaters, it has been found necessary to oil the cylinders as well as the valves, hence the need of the four-sight feed lubricator. Fig. 96 shows sections of a well-known make of a triple sight feed lubricator. The names of the parts are as follows:

1. CONDENSER
2. FILLING PLUG
3. HAND OILER
4. CHOKE PLUG or REDUCING PLUG
5. TAILPIECE
6. DELIVERY NUT
7. WATER VALVE
8. STUD NUT
9. SIGHT FEED GLASS AND CASING
9a. FEED NOZZLE
11. BODY
13. GAUGE GLASS AND CASING
14. WASTE COCK
15. REGULATING VALVES
16. TOP CONNECTION
17. EQUALIZING PIPE
18. OIL PIPE
19. WATER PIPE
20. SIGHT FEED DRAIN VALVE
21. EXTRA GLASS AND CASING
22. CLEANING PLUG
23. BODY PLUG
24. OIL PIPE PLUG
28. GAUGE GLASS BRACKET
29. CLEANING PLUG
30. GAUGE GLASS CAP

The lubricator is fastened to the boiler bracket by means of the stud nut, 8. In brief, the operation of the lubricator, as illustrated in Fig. 96, is as follows:

Steam is admitted to the condensing chamber, 1, through the boiler connection, 16. The steam condenses in the condenser and passes through the equalizing pipe to the bottom of the oil reservoir. The lubricator is filled at the filling plug, 2. As the condensed steam fills up the lubricator, the oil level is raised until the oil passes through the tubes, 18, to the regulating valve, 15, from whence it is permitted to pass drop by drop through the sight feed glass, 9, to the different conveying pipes. To fill the lubricator, first be sure that the steam valve is closed, then remove the filling plug and pour in the necessary amount of oil. After the filling plug has been replaced, open the steam valve slowly and let it remain open. After this, regulate the flow of oil by means of the regulating valves, 15.

Air Brake and Signal Equipment. The air brake and signal equipment are fully explained in the instruction book on the "Air-Brake" and will not be presented.

RAILWAY SIGNALING

Railway signaling is a very important subject and one to which a great deal of attention has been directed in recent years; it is by no means a new subject, however, nor has its development been rapid. It early became evident that signals are necessary in governing the movement of trains, so we find that as the traffic and speed of trains increased, the demand for improvements in signaling likewise increased.

Although there are a great many kinds of signals on the market, they may all be classed under four general types, namely, *audible, movable, train,* and *fixed signals.* The audible signal is well known as the bell, whistle, and torpedo.

Whistle Signals. One long blast of the whistle is the signal for approaching stations, railroad crossings, and junctions. (Thus ——.)

One short blast of the whistle is the signal to apply the brakes to stop. (Thus —.)

Two long blasts of the whisle is the signal to release the brakes. (Thus —— ——.)

Two short blasts of the whistle is an answer to any signal unless otherwise specified. (Thus — —.)

Three long blasts of the whistle to be repeated until answered is the signal that the train has parted. (Thus —— —— ——.)

Three short blasts of the whistle when the train is standing, to be repeated until answered, is a signal that the train will back. (Thus — — —.)

Four long blasts of the whistle is a signal to call in the flagman from the west or south. (Thus —— —— —— ——.)

Four long, followed by one short blast of the whistle, is the signal to call in the flagman from the east or north. (Thus —— —— —— —— —.)

Four short blasts of the whistle is the engineman's call for signals from switch tenders, watchmen, trainmen, and others. (Thus — — — —.)

One long and three short blasts of the whistle is a signal to the flagman to go back and protect the rear of the train. (Thus —— — — —.)

One long, followed by two short blasts of the whistle, is the signal to be given by trains when displaying signals for a following train to call the attention of trains of the same or inferior class to the signals displayed. (Thus —— — —.)

Two long followed by two short blasts of the whistle is the signal for approaching road crossings at grade. (Thus —— —— — —.)

A succession of short blasts of the whistle is an alarm for persons or cattle on the track and calls the attention of trainmen to the danger ahead.

Bell Cord Signals. One short pull of the signal cord when the train is standing is the signal to start.

Two pulls of the signal cord when the train is running is the signal to stop at once.

Two pulls of the signal cord when the train is standing is the signal to call in the flagman.

Three pulls of the signal cord when the train is running is the signal to stop at the next station.

Three pulls of the signal cord when the train is standing is the signal to back the train.

Four pulls of the signal cord when the train is running is the signal to reduce the speed.

When one blast of the signal whistle is heard while a train is running, the engineer must immediately ascertain if the train has parted, and, if so, take great precaution to prevent the two parts of the train from coming together in a collision.

Movable Signals. Movable signals are used to govern the movement of trains in switching and other service where demanded. They are made with flags, lanterns, torpedoes, fusees, and by hand. The following signals have been adopted as a standard code by the American Railway Association:

Flags of the proper color must be used by day and lamps of the proper color by night or whenever from fog or other cause, the day signals cannot be clearly seen.

Red signifies danger and is a signal to stop.

Green signifies caution and is a signal to go slowly.

White signifies safety and is a signal to continue.

Green and *white* is a signal to be used to stop trains at flag stations for passengers or freight.

Blue is a signal to be used by car inspectors and repairers and signifies that the train or cars so protected must not be moved.

An explosive cap or torpedo placed on the top of the rail is a signal to be used in addition to the regular signals.

The explosion of one torpedo is a signal to stop immediately. The explosion of two torpedoes is a signal to reduce speed immediately and look out for danger signals.

A fusee is an extra danger signal to be lighted and placed on a track at night in case of accident and emergency.

A train finding a fusee burning on the track must come to stop and not proceed until it has burned out. A flag or a lamp swinging across the track, a hat or any object waved violently by any person on the track, signifies danger and is a signal to stop.

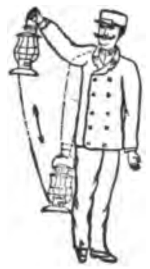


Fig. 97. Signal to Go Ahead.

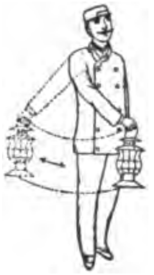


Fig. 98. Signal to Stop.

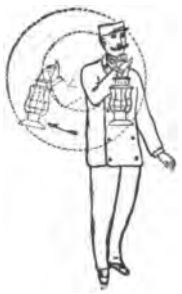


Fig. 99. Signal to Back Up.

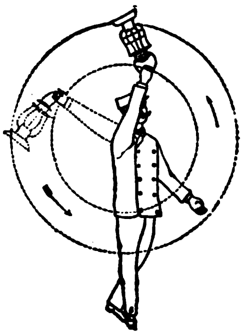


Fig. 100. Signal that Train has Parted.

The hand or lamp raised and lowered vertically is a signal to move ahead, Fig. 97.

The hand or lamp swung across the track is a signal to stop, Fig. 98.

The hand or lamp swung vertically in a circle across the track when the train is standing is a signal to move back, Fig. 99.

The hand or lamp swung vertically in a circle at arm's length across the track when the train is running is a signal that the train has parted, Fig. 100.

Train Signals. Each train while running must display two green flags by day, Fig. 101, and to green lights by night, one on each side of the rear of the train, as makers to indicate the rear of the train.

Each train running after sunset or when obscured by fog or other cause, must display the head light in front and two or more red lights in the rear, Fig. 102. Yard engines must display two green lights instead of red except when provided with a head light on both front and rear.

When a train pulls out to pass or meet another train the red lights must be removed and green lights displayed as soon as the track is clear, Fig. 103, but the red lights must again be displayed before returning to its own track.

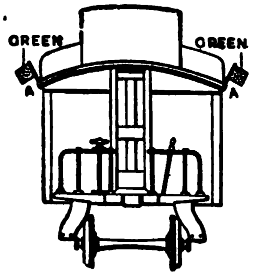


Fig. 101. Day Rear Signal.

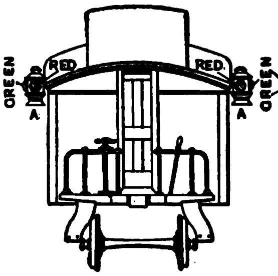


Fig. 102. Night Rear Signal.

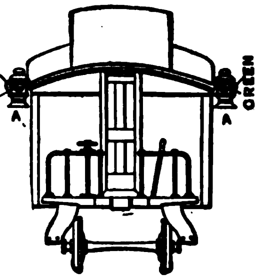


Fig. 103. Night Signal of a Clear Track.

Head lights on engines, when on side tracks, must be covered as soon as the track is clear and the train has stopped and also when standing at the end of a double track.

Two green flags by day and night, Fig. 104, and in addition two green lights by night, Fig. 105, displayed in places provided for that purpose on the front of an engine denote that the train is followed by another train running on the same schedule and entitled to the same time table rights as the train carrying the signals.

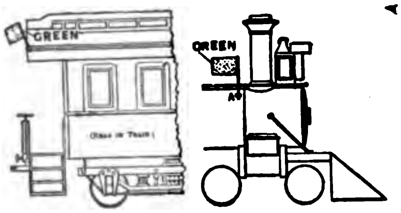


Fig. 104. Day Signal of a Train Behind.

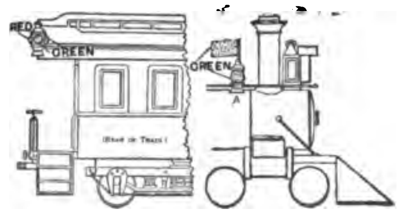


Fig. 105. Night Signal of a Train Behind.

An application of the above rules to locomotives running backward are shown in Figs. 106, 107, and 108.

Fig. 106 shows the arrangement of flags when a locomotive is running backward by day without cars, or pushing cars and carrying signals for a following train. There are two green flags, one at *A* and one at *B*, on each side. The green flag at *A* is a classification signal and that at *B* is the marker denoting the rear of the train.

Two white flags by day and night, Fig. 109, and in addition two white lights by night, Fig. 110, displayed in places provided for that purpose on the front of an engine, denote that the train is an extra. These signals must be displayed by all extra trains but not by yard engines.

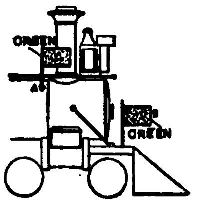


Fig. 106.

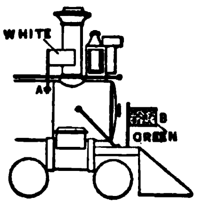


Fig. 107.

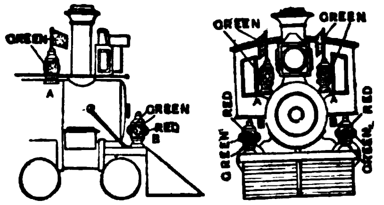


Fig. 108.

Signal of Train Behind or Locomotive Running Backward.

Fig. 107 shows the arrangement of flags on a locomotive which is running backward by day without cars or pushing cars and running extra. There is a white flag at *A* and a green one at *B*. The white flag is a classification signal and the green flag is the marker denoting the rear of the train.

Fig. 108 shows the arrangement of flags and lights on a locomotive which is running backward by night without cars or pushing cars and carrying signals for a following train. There is a green flag and light at *A* and a combination light at *B*. The green light and flag at *A* serve as a classification signal. The combination light at *B* is a marker showing green on the side and the direction in which the engine is moving and red in the opposite direction.

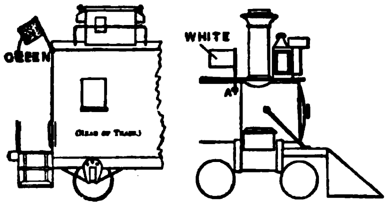


Fig. 109. Day Signal on Extra Train.

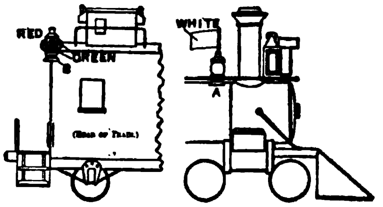


Fig. 110. Night Signal on Extra Train.

Fig. 110 shows the arrangement of flags and lights on a train running forward by night and running extra. There is a white flag and white light at *A* as a classification signal. At *B* there is a combination light. This combination light shows green to the sides and front of the train and red to the rear.

Fig. 111 shows the arrangement of flags and lights on a locomotive running backward by night without cars or pushing cars and running extra. There are white flags and white lights at *A A* as classification signals. At *B B* there are combination lights showing green on the sides and the direction in which the engine is running, and red in the opposite direction. The combination lights serve as markers.

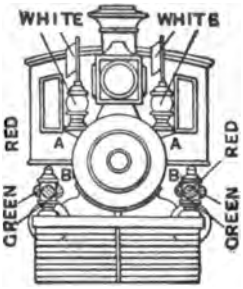


Fig. 111.
Night Signal on Locomotive Running Backward, as an Extra.

Fig. 112 shows the arrangement of green marker flags on the rear of the tender of a locomotive which is moving forward by day without cars.

Fig. 113 shows the arrangement of combination lights used as markers on the rear of the tender of a locomotive which is running forward at night without cars. The combination light shows green at the sides and front and red at the back.

Fig. 114 shows the arrangement of lights on the rear of the tender of a locomotive which is running backward by night. There is a single white light at *A*.

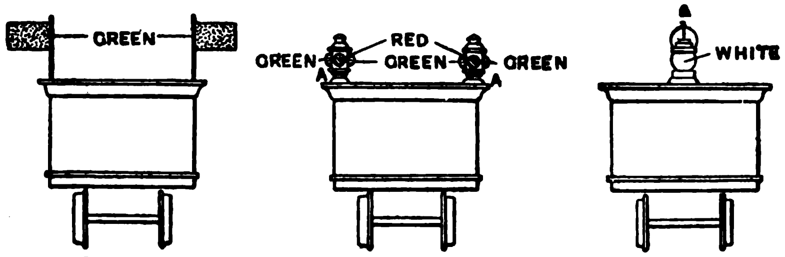


Fig. 112. Fig. 113. Fig. 114.
Signals on Tender for Engine Running Without Cars.

Fig. 115 shows the arrangement of lights on a passenger train which is being pushed by an engine at night. There is a white light at *A* on the front of the leading truck.

Fig. 116 shows the arrangement of lights on a freight train which is being pushed by an engine at night. There is a single white light at *A*.

Fixed Signals. Fixed signals consist in the use of posts or towers fixed at definite places and intervals having attached to them a system of rods, levers, and bell cranks to properly operate the arms or semaphores. The target is one form of fixed signal.

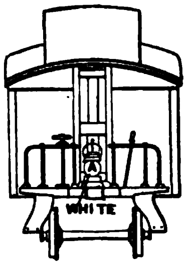


Fig. 115.
Night Signal for Passenger Train pushed by an Engine.

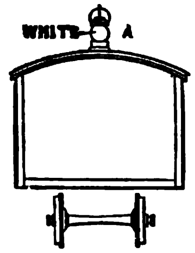


Fig. 116.
Night Signal for Freight Train Pushed by an Engine.

Targets are used to indicate, by form or color or both, the position of a switch. A target usually consists of two plates of thin metal at right angles to each other attached to the switch staff. The setting of the switch from the main line to a siding, for example, turns the staff through a quarter revolution thus exposing one or the other of the disks to view along the track. The disks or targets are usually painted red and white, respectively. When the red signal is exposed, the switch is set to lead off to the siding. When the white one is exposed, the switch is closed and the main line is clear. At night, a red and green or red and white light shows in place of the target.

The semaphore may now be considered as the standard method of controlling the movement of trains. It consists of an arm *A*, Fig. 117, pivoted at one end and fastened to the top of a post. When in the horizontal position, it indicates danger. When dropped to a position of 65 or 70 degrees below the horizontal, as in Fig. 118, it indicates safety.

At night, the semaphore is replaced by a light. There are two systems of light signals; one is to use a red light for danger, a green light for safety, and a yellow light for caution. The other is to use red for danger, white for safety, and green for caution. The method of operation is to have a lantern *B*, Fig. 118, attached to the left-hand side of the signal post in such a position that when the semaphore arm is in the horizontal position, the spectacle glass *C* will intervene between the approaching engine and the lantern as in Fig. 117. This spectacle glass is red. Where green is to be shown with a semaphore in the position shown in Fig. 118, the spectacle frame is double, as in Fig. 119, the upper glass being red and the lower green.

Semaphore arms are of two shapes, square at the ends as in Figs. 117, 118, and 119, and with a notched end, as in Fig. 120. The square ended semaphore is used for what is known as the *home* and *advanced signals*, and the notched end for *distance signals*. Semaphores are set so as to be pivoted at the left-hand end as viewed from an approaching train. The arm itself extends out to the right.

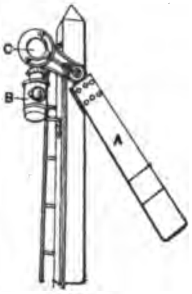


Fig. 118. Semaphore set at Safety.

The use of home, distance, and advanced signals is as follows: The railroad is divided into blocks at each end of which a home signal is located. When the home signal is in a horizontal position or danger position, it signifies that the track between it and the next one in advance is obstructed and that the train must stop at that point.

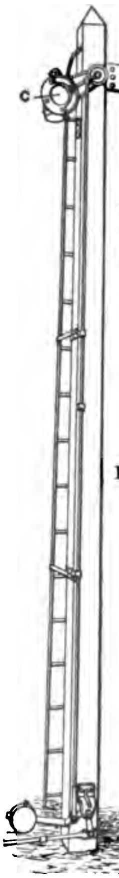


Fig. 117. Semaphore Set at Danger Signal.

The distance signal is placed at a considerable distance in front of the home signal, usually from 1,200 to 2,000 feet, and serves to notify the engineer of the position of the home signal. Thus, if when he passes a distance signal, the engineer sees it to be in a horizontal position, he knows that the home signal is in the danger position also and that he must be prepared to stop at that point unless it be dropped to safety in the meantime. The distance signal should show the cautionary light signal at night.

The advanced signal is used as a supplementary home signal. It is frequently desirable, especially at stations, to permit a train to pass a home signal at danger in order that it may make a station stop and remain there until the line is clear. An arrangement of block signals is shown in Fig. 121. There are three home signals *A*, *B*, and *C* on the west bound track, the distance between them being the length of the block. This distance may vary from 1,000 feet to several miles. *D*, *E*, and *F* are the corresponding home signals for the east bound track. The distance signals *G*, *H*, *I*, and *K* protect the home signals *B*, *C*, *E*, and *F*; *L* is the advanced signal at the station *M* for the home signal *B*. Thus, a train scheduled to stop at *M* will be allowed to run past the home signal at *B* when it is at danger and stop in front of the advanced signal *L*. When *L* is lowered to safety, the train can move on.

The signals of the block are usually interlocked, that is, one signal cannot be moved to danger or safety until others have been moved. The signals of two succeeding stations are also interlocked, usually electrically.

Block System. The term *block* as used above applies to a certain length of track each end of which is protected by means of a distance and home signal. The length of a block varies through wide limits depending upon the nature of the country, amount of traffic, and speed of trains. The heavier the traffic, the more trains there are to be run, so it is desirable to run the trains as close together as possible. Hence, the blocks should be as short as safety will permit. On the other hand, as the speed of the train increases, the time required to pass over a given distance is diminished, hence the length of a block may be increased. The length of the block differs for single-, double-, and four-track roads. Ordinarily the blocks are from ten to twelve miles long. There are a number of different kinds of block systems named as follows, according to the way in which they are operated: the

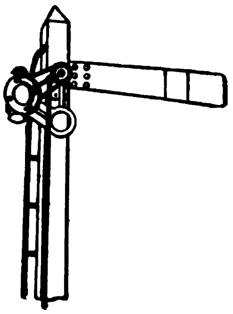


Fig. 119. Home Semaphore Signal.

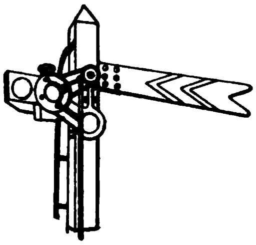


Fig. 120. Distance Semaphore Signal.

staff, controlled manual, automatic, and *telegraph* systems. All of these systems are similar in their principle of operation, differing only in the means used in securing the desired results. For instance, the controlled manual is operated by a tower man but the mechanism is partly automatic so that he cannot throw his signals until released by mechanism at the other end of the block which electrically locks his signals.

The working of the lock and block system between two stations *A* and *B*, Fig. 121, is as follows: When a train approaches *A*, the operator pulls his signal to clear, provided there is no other train in the block. As the train passes the signal and over a short section of insulated track, the wheels short circuit the track which carries an electric current. This action operates electrical apparatus which permits the semaphore arm to go to the danger position by force of gravity. After the operator has cleared the signal, an electric locking machine works in such a way that the signal cannot again be cleared until the train has passed over another section of insulated track as it passes out of the block at the station *B*. When the train passes this second section of track and short circuits the track, an electric current is automatically sent back through line wires to *A* and unlocks the machine, giving the operator at *A* permission again to clear his signal permitting another train to enter the block.

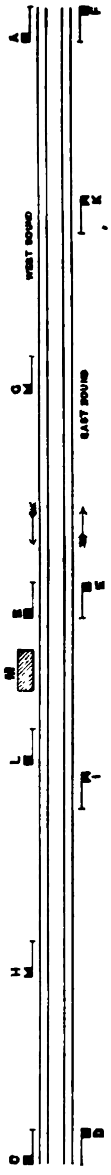


Fig. 121. Diagram of Lock and Block System.

The above description of the lock and block or controlled manual system will make clear the following established principles of interlocking:

1. *Each home signal, lever in that position which corresponds to the clear signal must lock the operating levers of all switches and switch locks which, by being moved during the passage of a train running according to that signal, might either throw it from the track, divert it from its intended course, or allow another train moving in either direction to come into collision with it.*

2. *Each lever so locked must in one of its two positions lock the*

original home signal in its danger position, that position of the lever being taken which gives a position of switch or switch lock contrary to the route implied by the home signal when clear.

3. *Each home signal should be so interlocked with the lever of its distance signal that it will be impossible to clear the distance signal until the home signal is clear.*

4. *Switch and lock levers should be so interlocked that crossings of continuous tracks cannot occur where such crossings are dependent upon the mutual position of switches.*

5. *Switch levers and other locking levers should be so interlocked that the lever operating a switch cannot be moved while that switch is locked.*

Levers at one signal station are locked from the station in advance. Thus, the signal *A*, Fig. 121, cannot be put to clear until freed by the operator at *B*. *B* cannot be cleared until freed by *C*, etc. Levers and signals may be operated by hand, pneumatic, or electric power, the last two either automatically or by an operator.

Hall Signal. Disk signals are also used for block signaling and are usually automatic. The Hall signal, illustrated in Fig. 122, is an example of this kind. It consists of a glass case *A* containing electric apparatus operated by a current controlled by the passage of a train. When the block is closed, a red disk fills the opening *B* by day, and a red light shows at *C* by night. A clear signal is indicated by a clear opening at *B* by day and a white light at *C* by night.

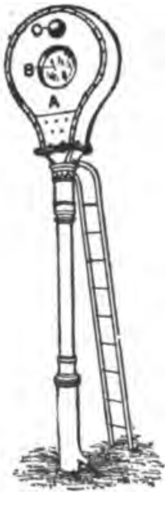


Fig. 122. Hall Disk Signal.

When a single track is to be operated by block signals, it is customary to put two semaphores on one pole, as shown in Fig. 123. The arm extending to the right as seen from an approaching train is the one controlling the movement of that train.

Dwarf Signals. These are in all respects similar to the regular semaphore differing only in their size. They are usually short arms painted red, standing from two to four feet from the ground, and are similar to the home signal. They are used only to govern movement for trains on secondary tracks or movements against the current of traffic on main tracks when such reverse movement becomes necessary, and where necessary in yards. They are especially used for governing the movement of trains in backing out of train sheds at terminals.

Absolute and Permissive Block Signaling. Block signaling should always be absolute, that is, when the home signal is at danger no trains should be allowed to pass. It should never be cleared until the whole block in advance is emptied; that is, the signal at *B*, Fig. 121, should never be set to clear until the last preceding train has passed the home signal at *C*.

Permissive signaling introduces a time element into the system and is practiced by many roads. Thus, when a certain time, usually from 5 to 10 minutes, has elapsed after a train has passed a home signal, a following train is allowed to proceed though the signal still remains at danger. The following train is notified of the occupancy of the block by the preceding train by the display of a cautionary signal, usually a green flag or light from the tower at the signal so passed. It is a dangerous system and one subversive of good discipline and safety.

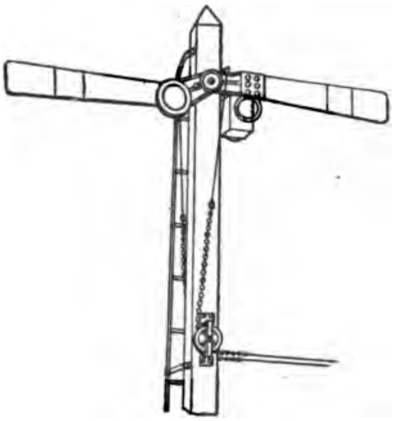


Fig. 123. Semaphore Block Signal for Single Track.

LOCOMOTIVE OPERATION

Running. The actual handling of a locomotive on the road can only be learned by practice with the engine itself. There are, however, certain fundamental principles which must be borne in mind and applied.

FIRING. Before taking charge of a locomotive, a considerable period must be spent as a fireman. The first things to be learned are the principles governing the composition of fuels.

The difference between the work of a locomotive boiler furnace and one under a stationary boiler is that in the former the rate of fuel consumption is very much greater than in the latter. In locomotive boilers it often occurs that 150 pounds of bituminous coal is burned per square foot of grate area per hour while a consumption of 200 pounds per square foot per hour is not unusual.

Different fuels require different treatment in the fire-box.

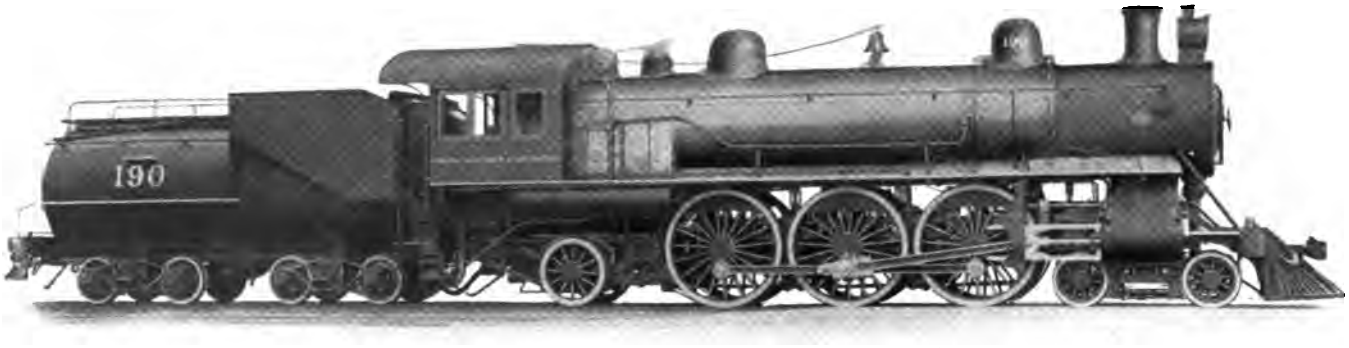
Bituminous coal is the most common fuel used on American railroads. It varies so much in chemical composition and heat value that no fixed rule for burning it can be laid down. The work of the fireman varies more or less with each grade of coal used. Ordinarily, the fuel bed should be comparatively thin. It may vary in thickness from 6 to 10 inches or even more, depending on the work the locomotive is called upon to perform. The fuel bed should be of sufficient thickness to prevent its being lifted from the grate under the influence of the draft created by the exhaust.

In order to obtain the best results, the stoking must be very nearly constant. Three shovelfuls at a time have been found to give very good results. The fire door should be closed between each shovelful so as to be only open on the latch. This delivers air to complete the combustion of the hydrocarbon gases which are distilled the moment the fresh coal strikes the incandescent fuel. In placing the fuel in the fire-box, it is well to heap it up slightly in the corners and allow the thinnest portion of the bed to be in the center of the grate. The frequency of the firing depends upon the work the engine is called upon to do.

The fire should always be cleaned at terminals and when the grade is favorable the slice bar may be used and the clinker removed through the furnace door while running.

Anthracite coal. In using anthracite coal, it is best, whenever possible, to do the stoking on favorable grades and at stations. The thickness of the fuel bed varies in size with the kind of coal used. It may vary from three inches with fine pea and buckwheat coal to 10 inches with large lumps. The fuel should be evenly distributed over the entire grate. The upper surface of an anthracite coal fire must never be disturbed by the slice bar while the engine is working. When it is necessary to use the slice bar, it should be done only when there is ample time after its completion to enable the fire to come up again and be burning vigorously before the engine resumes work.

Feeding the Boiler. Feeding the boiler is a matter requiring skill and judgment, especially where the locomotive is being worked to its full capacity. The injector is now the universal means em-



PACIFIC TYPE, PASSENGER LOCOMOTIVE
American Locomotive Co.

ployed for feeding the locomotive boiler. Where it is possible, the most satisfactory way is to use a constant feed which will be average for the entire trip. In this way the water level will rise and fall but will always be sufficient to cover the crown sheet. Under no circumstances should the water level be allowed to fall below the lower gauge cock.

Where a constant feed cannot be used, the injector may be worked to its full capacity on favoring grades and at station stops. This will give a storage of water to be drawn upon when the engine is working to its full capacity on adverse grades. Under such circumstances, the stopping of the feed may enable the fire to maintain the requisite steam pressure, whereas the latter might fall if the injector were to be kept at work. Further, the use of the injector on down grades and at stations keeps down the steam pressure and prevents the loss of heat by the escape of steam through the safety valves when the fire is burning briskly and the engine is not working.

THE USE OF STEAM. The manner in which an engineer uses the steam in the cylinders is one of the controlling elements in the economical use of coal. In starting, the reverse lever must be thrown forward so that steam is admitted to the cylinders for as great a portion of the stroke of the piston as the design of the valve motion will permit. As the speed increases, the lever should be drawn back, thus shortening the cut-off. It will usually be found that when the engine is not overloaded, a higher speed will be attained and maintained with a short than with a long cut-off. The reason is that with a late cut-off, so much steam is admitted to the cylinder that it cannot be exhausted in the time allowed, resulting in an excessive back pressure which retards the speed.

Experiments have proven, however, that it is not economical to use a cut-off which occurs earlier than one-fourth stroke, for when the cut-off occurs earlier than this, the cylinder condensation will more than offset the saving effected by the increased expansion so obtained. For this reason when the engine is running under such conditions that a cut-off earlier than one-fourth stroke can be used with the throttle wide open, it may be better to keep the point of cut-off at one-fourth stroke and partially close the throttle, thus wiredrawing the steam. The wiredrawing of the steam serves to superheat it to a limited extent and thus to diminish the cylinder condensation which would occur were saturated steam at the same pressure being used.

When running with the throttle valve closed, the reverse lever should be set to give the maximum travel to the valve in order to prevent the wearing of the shoulders on the valve seats.

LEARNING THE ROAD. Learning the road is one of the most important things for the engineer to accomplish. He must know every grade, curve, crossing, station approach, bridge, signal and whistle or bell post on the division over which he runs. He must know them on dark and stormy nights as well as in the daytime. He must always know where he is and never be at the slightest loss as to his surroundings. He must not only know where every water tank is located but should also make himself familiar with the qualities of the various waters they contain. Then when he has a choice of places at which to take water he may choose that containing the mallest amount of scale-forming matter.

Grades. In the learning of a road an intimate knowledge of the grades is of the first importance to the engineer. He must know what his engine can handle over them, how it must be handled when on them, and how they must be approached. An engine will frequently be able to take a train over a grade if it has a high speed at the foot, whereas if a stop or slackening of the speed were to be made at the foot of the grade it would be impossible to surmount it with the entire train.

Handling Trains. Handling trains over different profiles of track requires different methods. On adverse grades, the work is probably the simplest. In such conditions the train is stretched out to its fullest extent. Every car is pulling back and the checking of the movement of the front of the train meets with an immediate response throughout the whole train. The grade also prevents sudden acceleration at the front. It is, therefore, necessary merely to keep the engine at work.

On favoring grades, the whole train when drifting is crowding down upon the locomotive and is likely to be bunched or closed together. Under these conditions, it is necessary to apply the air brakes which are at the front end and keep them applied so as to hold the speed under control and prevent the train from running away. Care should be taken in the application of the driving wheel brakes on long down grades lest the shoes heat the tires and cause them to become loose.

The greatest danger of injury to a train arises in passing over ridges and through sags. First, in leaving an adverse grade in passing over a ridge to a favoring grade, the engineer must be careful not to accelerate the front end of the train too rapidly lest it break in two before the rear end has crossed the summit. There is greater danger, however, in running through a dip where the grade changes from a favoring to an adverse one. Where brakes have been applied at the rear of the train and the slack prevented the train from becoming bunched, there is not the same danger as when the brakes have been applied at the front of the train. In the latter case, if the engineer is not careful in pulling out the slack, the train may be parted. Accidents of this class will be minimized if in every case the slack is taken up slowly. A steady pull will not break the draft rigging of the car, whereas a sudden jerk may pull it out.

In case a train does break in two, the engine and front portion should be kept in motion until the rear portion has been stopped. In so doing a collision may be avoided. Where air brakes are applied to the entire train, the rear portion will stop first owing to the proportional increase of weight and momentum of the locomotive.

Freight trains require on the whole more careful handling than passenger trains. There is more slack in the couplings of the former than in the latter and the trains are much longer, consequently the shocks at the rear of a freight train, due to variation in speed, are much more severe than on passenger trains. The system of handling, while practically the same for both classes, requires more care in order to avoid accidents with a freight train than with a passenger train.

THE END OF THE RUN. When the run has been finished, the engineer should make a careful inspection of all parts of the engine so as to be able to report any repairs which may be needed in order to fit the locomotive for the next run. The roundhouse hostler should then take the engine and have the tender loaded with coal, the tank filled with water, and the fire cleaned. The engine should then be put over the pit in the roundhouse, carefully wiped, and again inspected for defects.

Inspection. The inspection of locomotives should be thorough. It should embrace the condition of every exposed wearing surface and the behavior of every concealed one. All bolts and nuts should be examined to ascertain if they are tight. The netting in the front end should be examined at frequent intervals to make sure that it is not burned out. The stay-bolts should be inspected periodically in order that those broken may be replaced. Wheels and all parts of the running gear and mechanism should be carefully scrutinized for cracks or other defects.

Cleaning. Cleaning the engine should be done after every trip, since dust and dirt may cover defects which may be serious and ultimately cause a disaster.

Repairs. Repairs of a minor nature can be made in the roundhouse and should receive prompt attention. Roundhouse repairs include such work as the replacing of the netting in the smoke-box, cleaning of nozzles, expanding and caulking leaky flues, refitting the side and connecting rod brasses, refitting valve seats, regrinding leaky cab fittings, adjusting driving box wedges, repairing ash pans, replacing grates, renewing brake shoes, resetting valves, repairing water tanks, and sometimes may be extended to the re-boring of cylinders. To this list must also be added the regular work of renewing all packing and cleaning out the boiler.

Emergencies. Emergencies are constantly arising in locomotive running where a breakage of some part should be repaired while on the road. The part affected and the extent of the fracture has much to do with the possibility of running the engine home under its own steam. A few methods of dealing with the more common breakages will be given.

Broken Side Rods. If a side rod breaks, the ends of the broken rod should be disconnected and the rod on the opposite side of the engine should be removed. An attempt should never be made to run a locomotive with only one side rod connected as the engine would be badly out of balance and trouble would arise when the driver attempted to pass the dead center.

Broken Connecting Rod. If a connecting rod is broken without injury to the cylinder, the crosshead and piston should be blocked at one end of the stroke and the broken parts of the rod removed. The removal of the side rods depends upon the extent of injury to the crank pin on the broken side. All side rods should be left in position if the crank pin on the broken side is uninjured, otherwise all should be removed. The valve rod should be disconnected from the rocker arm and the valve stem clamped with the valve in the central position.

The valve stem may be clamped by screwing down one of the gland nuts more than the other, thus cramping the stem. It may also be secured by the use of the clamp shown in Fig. 124. This consists of two parts having V-shaped notches which are securely fastened to the valve stem by a bolt on either side. This is done after having passed the gland studs through the two slotted holes, which prevents any longitudinal movement of the stem after the nuts on the studs have been screwed home. The crosshead should be forced to one end of the guides with the piston against the cylinder head. In this position, it can be secured by a piece of wood cut to fit snugly between it and the guide yoke.

When the parts on one side have been blocked in this way, the engine can be run to the shop with one side working.

Broken Driving Springs. In case a driving spring breaks, a block of wood should be inserted between the top of the driving box and the frame. This can be done by first removing the broken spring and its saddle, then running the other drivers on wedges to lift the weight off the driver with the broken spring. The piece of wood should then be inserted and the pair of drivers run up on wedges. After this is done, the fallen end of the equalizing lever should be pried up until it is level and blocked in this position. All parts which are liable to fall off should be removed.

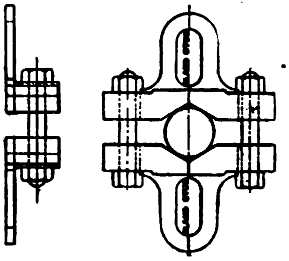


Fig. 124. Clamp for Repair of Broken Connecting Rod.

Low Water. If for any reason the water gets low in the boiler or if through accident some of the heating surface is laid bare, the fire should be dampened by throwing dirt into the fire-box. A stream of water should never be turned on the fire.

Foaming. If foaming occurs, the throttle should be slowly closed. This prevents the water height dropping suddenly and uncovering the crown sheet. If there is a surface blow-off, it should be opened and the impurities on the surface of the water blown off. If the foaming is caused by grease which has collected in the tank, the tank should be overflowed at the next water station and a couple of quarts of unslacked lime placed in it. If this cannot be obtained, a piece of blue vitriol, which may be obtained at almost any telegraph office, may be placed in the hose back of the screen.

Broken Steam Chest. In case a steam chest becomes fractured, either the lower joint of the steam pipe on the side of the accident should be pried open and a blind wooden gasket inserted, or the steam chest and valve should be removed and a piece of board laid over the steam openings and firmly clamped in position by the studs of the steam chest.

The above are a few of the accidents which may occur on the road. To prepare for emergencies, the best method is to study the locomotive and devise means of making temporary repairs for every accident imaginable, then when the accident does occur, the remedy can be promptly applied.

TRAIN RULES

The American Railway Association has adopted a uniform code of train rules which have been accepted by the railroads of the United States. These rules briefly stated are as follows:

All trains are designated as regular or extra and may consist of one or more sections. An engine without cars in service on the road is considered a train.

All trains are classified with regard to their priority of right to the track.

A train of an inferior class must in all cases keep out of the way of a train of a superior class.

On a single track all trains in one direction specified in the time table have the absolute right of track over trains of the same class running in the opposite direction.

When trains of the same class meet on a single track, the train not having the right of track must take the siding and be clear of the main track before the leaving of the opposite train.

When a train of inferior class meets a train of a superior class on a single track, the train of inferior class must take the siding and clear the track for the train of superior class five minutes before its leaving.

A train must not leave a station to follow a passenger train until five minutes after the departure of such passenger train unless some form of block signaling is used.

Freight trains following each other must keep not less than five minutes apart unless some form of block signaling is used.

No train must arrive at or leave a station in advance of its scheduled time.

When a passenger train is delayed at any of its usual stops more than — minutes, the flagman must go back with a danger signal and protect his train, but if it stops at any unusual point, the flagman must immediately go back far enough to be seen from a train moving in the same direction when it is at least — feet from the rear of his own train.

When it is necessary to protect the front of the train, the same precautions must be observed by the flagman. If the fireman is unable to leave the engine, the front brakeman must be sent in his place.

When a freight train is detained at any of its usual stops more than — minutes, where the rear of the train can be plainly seen from a train moving in the same direction at a distance of at least — feet, the flagman must go back with danger signals not less than — feet, and as much farther as may be necessary to protect his train but if the rear of his train cannot be plainly seen at a distance of at least — feet, or if it stops at any point which is not its usual stopping place, the flagman must go back not less than — feet, and if his train should be detained until within ten minutes of the time of a passenger train moving in the same direction, he must be governed by rule No. 99.

Rule No. 99 provides that when a train is stopped by an accident or obstruction, the flagman must immediately go back with danger signals to stop any train moving in the same direction. At a point — feet from the rear of his train, he must place one torpedo on the rail. He must then continue to go back at least — feet from the rear of his train and place two torpedoes on the rail ten yards apart (one rail length), when he may return to a point — feet from the rear of his train, where he must remain until recalled by the whistle of his engine. But if a passenger train is due within ten minutes, he must remain until it arrives. When he comes in, he will remove the torpedo nearest to the train but the two torpedoes must be left on the rail as a caution signal to any train following.

When it is necessary for a freight train on a double track to turn out on to the opposite track to allow a passenger train running in the same direction to pass, and the passenger train running in the opposite direction is due, a flagman must be sent back with a danger signal as *provided in Rule No. 99 not less than —feet in the direction of the following train and the other train must not cross over until one of the passenger trains arrive. Should the following passenger train arrive first, a flagman must be sent forward on the opposite track with danger signals as provided in Rule No. 99, not less than —feet in the direction of the overdue passenger train before crossing over. Great caution must be used and good judgment is required to prevent detention to either passenger train. The preference should always be given the passenger train of superior class.*

If a train should part while in motion, trainmen must use great care to prevent the detached parts from coming into collision.

Regular trains twelve hours or more behind their scheduled time lose all their rights.

All messages or orders respecting the movement of trains or the condition of track or bridges must be in writing.

Passenger trains must not display signals for a following train without an order from the Superintendent, nor freight trains without an order from the Yard Master.

Great care must be exercised by the trainmen of a train approaching a station where any train is receiving or discharging passengers.

Engine men must observe trains on the opposite track and if they are running too closely together, call attention to the fact.

No person will be permitted to ride on an engine except the engineman, fireman, and other designated employes in the discharge of their duties without a written order from the proper authorities.

Accidents, detentions of trains, failure in the supply of water or fuel, or defects in the tracks or bridges must be promptly reported by telegraph to the Superintendent.

No train shall leave a station without a signal from its conductor.

Conductors and engine men will be held equally responsible for the violation of any rules governing the safety of their trains and they must take every precaution for the protection of their trains even if not provided for by the rules.

In case of doubt or uncertainty, no risks should be taken.

TIME TABLES

Time tables are the general law governing the arrival and leaving time of all regular trains at all stations and are issued from time to time as may be necessary. The time given for each train on the time table is the scheduled time of such trains.

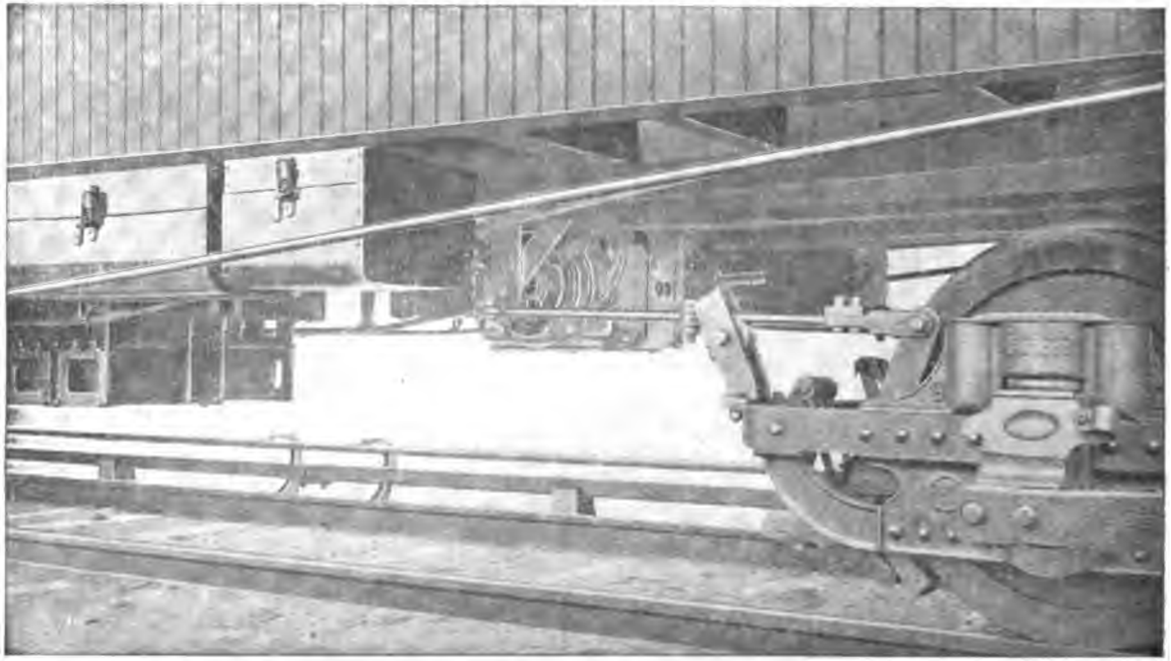
Each time table from the moment it takes effect supersedes the preceding time table and all special relations relating thereto and trains shall run as directed thereby, subject to the rules. All regular trains running according to the preceding time table shall, unless otherwise directed assume the times and rights of trains of corresponding numbers on the new time table.

On the time table, not more than two sets of figures are shown for a train at any point. When two times are shown, the earlier is the arriving time and the later, the leaving time. When one time is shown, it is the leaving time unless otherwise indicated.

Regular meeting or passing points are indicated on the time table.

The words "Daily," "Daily except Sunday," etc., printed at the head and foot of a column in connection with a train indicate how it shall be run. The figures given at intermediate stations shall not be taken as indicating that a train will stop, unless the rules require it.

Trains are designated by numbers indicated on the time table.



Under Section of Electric Car Showing Air Compressor, made by General Electric Co.

THE AIR-BRAKE

INTRODUCTION

The development of the many accessory appliances with which the rolling stock of our railways is fitted, has been the subject of a great deal of study and investigation. Of the many appliances which have received careful and systematic study, the braking apparatus may be mentioned as one of the most important.

The time when the question of braking first received attention dates back further than the time when highways became sufficiently well made and well maintained to permit of vehicles being drawn at a moderate rate of speed. When wheeled vehicles, drawn at speeds of 10 or 15 miles per hour, first made their appearance, it was found necessary to provide means by which they could be easily and quickly stopped in case of an emergency. The first carts and wagons, built for agricultural purposes, were of such construction that the resistance of the earth and axle were sufficient to bring them to rest in a reasonable length of time on ordinary roads. In cases of steep grades, the motion was retarded by one or both wheels being locked with chains, or by a stone or piece of timber being chained to the axle and dragged along the ground behind the vehicle.

It is interesting to note that the question of braking has steadily increased in importance as the demand for higher speed has increased. This applies equally well to all classes of vehicles, including railway trains, street and interurban cars, automobiles, and wagons. The first forms of braking apparatus adopted have formed the basis of almost all brake appliances which have since been employed for the same class of vehicles.

Early Forms of Brake. Perhaps one of the first forms of brake used was that found on the early stage-coach. It consisted of an iron shoe which was chained to the fore part of the coach, and was used only on steep grades. To apply this brake, the shoe was removed from its hook under the carriage and placed on the ground in front of the rear wheel, in such a position that the wheel would roll on it. As the wheel rolled on the shoe, the chain became taut, with the result that both the shoe and wheel slid over the surface of the ground.

A railroad is known to have existed as early as 1630, although it would hardly be called by that name to-day. The construction of the track as well as that of the cars, was almost entirely of wood. Even with this crude construction, it was found necessary to provide a brake to control the speed of the cars on the slight grades. The form of brake devised to meet the conditions consisted of a wooden lever pinned to the frame of the car at one end, in such a manner as to permit of its being pressed against the tread of the wheel by hand. When not in use, the lever was held off the wheel by means of a chain. The principle employed here in resisting the motion of the car, is the same as that employed to-day on all railroads—namely, of *applying the braking or resisting force to the periphery of the wheel.*

As railroads increased in number and their construction improved, braking apparatus became more and more a necessity. As a result, inventors brought out a number of simple braking appliances. The question of braking, however, did not become a very important or serious one until the advent of the steam locomotive. Previous to its coming, the cars were small and were drawn by animals, and the speeds were low; but with the steam locomotive in existence, an efficient brake became an absolute necessity.

This problem received the close attention of inventors and investigators; and at the close of 1870, the *automatic*, *electromagnetic*, *steam*, *vacuum*, and *air brakes* were found in use on the railroads in the United States. These types of brakes differed chiefly in the manner in which the braking power was obtained. Other devices were invented, but could not stand the test of actual practice and did not come into prominence.

It might be interesting to note briefly one or two rather unique types of brakes not included in any class yet mentioned. The *Cramer Brake*, brought out in 1853, might be mentioned as one of these. Its principal feature consisted of a spiral spring which was connected to the brake-staff at the end of each car. This spring was wound up by the brakeman before leaving the station. The brake apparatus on each car was under the control of the engineer, through the medium of a cord. This cord was connected to the mechanism of each brake, and passed through the cars, terminating in the cab on the engine. The engineer, desiring to stop his train, would shut off the steam and give the cord a pull, which action resulted in releasing the coil springs on the various cars, and applied the brakes by winding up the brake-chains.

The *Loughridge Chain Brake* is another unique brake, which was introduced in 1855. The Loughridge brake consisted of a combination of rods and chains which extended from a winding drum under the engine, throughout the entire length of the train. This continuous chain joined other chains under each car, which in turn were connected to the brake-levers. The winding drum located under the engine was connected by a worm gear to a small friction wheel. In operating the brake, a lever in the cab was thrown, which brought the small friction wheel in contact with the periphery of one of the driving wheels, thereby causing the drum to rotate and wind up the chain. The movement of the chain, which was experienced throughout the entire length of the train, served to actuate levers and rods under each car, which in turn applied the brake-shoes to the treads of the wheels.

The early types of hand-brakes underwent many improvements as years went on and as experience demanded. Although during many years of early railroading, the braking on all trains was done by hand, nevertheless there was a constant desire and demand for a practical automatic brake. The rather crude and inefficient types of brakes already referred to were obtained only after a great many failures. Since about 1870, all forms of brakes have differed chiefly in but one respect—namely, in the appliances which are used in operating the foundation brake-gear. The foundation brake-gear is made up of the rods, levers, pins, and beams, located under the frame of the car, the operation of which causes the brake-shoes to be pressed against the periphery or tread of the wheel. The present scheme of applying the brake-shoe to the periphery of the car wheel —which was in use long before the first locomotive made its appearance—later experience has proven to be the most practical.

Many forms of brakes were devised prior to the year 1840; but, at that time, few locomotives were equipped with braking apparatus. About this period, however, when the locomotive tender began to take on some definite form, we find the tender fitted with braking appliances. Previously, when brakes were provided, they were usually found fitted to the cars only. It is only within the last thirty-five years that locomotives have been built with brakes fitted to the drivers. To-day it is not uncommon to find all wheels on both the locomotive and the tender equipped with braking apparatus.

In 1869, the first Westinghouse air-brake made its appearance. This brake is now referred to as the *Straight Air-Brake*. It was not an automatic brake. It consisted chiefly of a steam-driven air-compressor and storage reservoir located on the engine; a pipe line extending from this reservoir throughout the length of the train; a brake-cylinder on each car; and a valve located in the cab for controlling the brake mechanism. The train line was connected between cars by means of flexible rubber hose with suitable couplings. Each car was fitted with a simple cast-iron brake-cylinder and piston, located underneath the frame, the piston-rod of which connected with the brake-rigging in such a manner that when air was admitted into the cylinder, the piston was pushed outward and the brake thereby applied. In operating the brake, air was admitted into the train line from the storage reservoir by means of a three-way cock located in the cab. The air was conducted to the brake-cylinder under the various cars by means of the train-pipe. The release of the brakes was accomplished by discharging the air in the various brake-cylinders and the train-pipe, into the atmosphere, through the three-way cock in the cab. This was the simplest and most efficient brake invented up to the time of its appearance, and was adopted by many railroad companies in this country.

The *Straight Air-Brake* system, however, possessed three very objectionable features: *First,* in case of a break-in-two, or of a hose bursting, the brake at once became inoperative; *second,* it was very slow to respond in applying and releasing the brakes; and, *third,* the brakes on cars nearest the engine were applied first, causing jamming and surging of the cars, which sometimes proved destructive to the equipment. In order to overcome these undesirable qualities, Mr. George Westinghouse invented the *Westinghouse Automatic Air-Brake* in 1872. This form of brake, which has since gone out of service on steam railroads, was known as the *Plain Automatic Air-Brake.* This brake retained the principal features of the *Straight Air-Brake;* but, in addition, each car was provided with an air-reservoir, which supplied air for operating its particular brake-cylinder. The charging with air of this *auxiliary reservoir,* the admitting of this air into the brake-cylinder, and the discharge of the air from the brake-cylinder to the atmosphere, were accomplished by an ingenious device known as the *triple valve.* A detailed description of this valve will be given later.

In this same year (1872), the *Vacuum Brake* was invented; but, on account of its many undesirable features, it never gained very great prominence in this country. This brake was spoken of as the *Plain Vacuum Brake,* and was followed later by the *Automatic Vacuum Brake.* The principal parts of the air-brake were, in general, embodied in the Vacuum brake. One marked difference existed, however, in that, instead of an air-compressor, an *ejector* was installed on the locomotive, which exhausted the air from the train-pipe when the system was in operation.

At the close of the year 1885, there could be found in use on the railroads of the United States a number of different types of brakes. These could be grouped into two general classes—*Continuous* or *Air* brakes, and *Independent* or *Buffer* brakes. In the Buffer brake, the brake-shoes were actuated by rods and levers, which in turn received their motion from the movement of the draw-bar. It is easily seen that, with such a variety of different forms of braking apparatus, it would be impossible to control a train properly if it were made up of cars from different railroads having different brake systems.

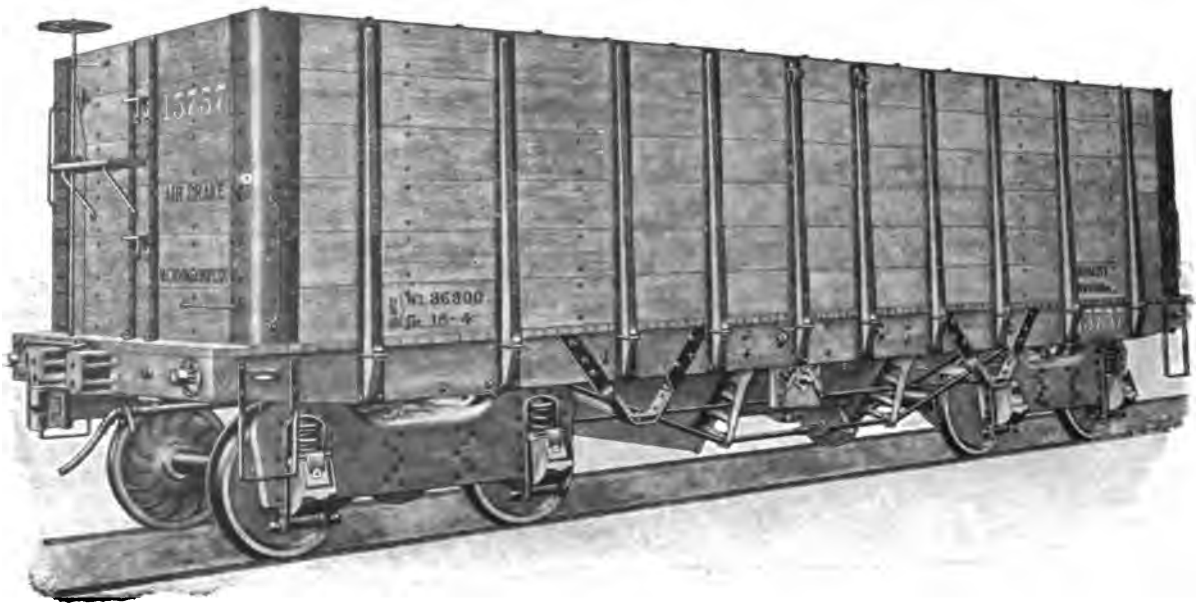
Interchangeable Brake System. The one agency which has had an important part in placing the braking appliances of our railroads on the present high standard of perfection, is the Master Car-Builders' Association. This Association, realizing the increasing demand for the interchange of cars, saw the need of interchangeable brake systems. It was principally through the research of their committees that the brake systems of to-day are interchangeable and efficient.

The first experiment conducted by the committee in 1886 clearly showed that any further attempt to use the Independent or Buffer brake was not desirable, on account of the severe shocks resulting when stopping the train. The effect of the report of the committee was the withdrawal of this type of brake from the attention of the railroad officials. This left almost the entire field open to the Continuous or Air brake system. The committee continued its work the following year, and, from the results of a large number of tests, reported that the best type of brake for long freight trains was one operated by air, in which the valves were actuated by electricity. This type of brake stopped the train in the shortest possible distance, reduced all attending shocks to a minimum, was released instantaneously, and could be applied gradually. Although the results of tests pointed to the superiority of the air-brake in which the valves were operated by electricity, yet to-day we find no such systems in general use.

From the time of these tests, the different brake companies turned their attention to the style of brake represented by the Westinghouse Automatic Air-Brake system. In this system, the most important parts are the *triple valve*, located on the brake-cylinder of each car, and the *controlling* or *engineer's brake-valve* located in the cab. By the year 1893, a number of triple valves and engineer's brake-valves had been placed on the market, and representative ones were exhibited at the Columbian Exposition in Chicago in that year.

The committee of the Master Car-Builders' Association, being conscious of the fact that the actions of the valves made by the different companies were so widely different, proposed a series of tests of triple valves, and asked the different companies to submit valves for the said tests. The object of the proposed tests was to obtain data from which could be formulated a code of tests for triple valves which would be satisfactory to all parties concerned. The ultimate aim of the committee was to secure triple valves which would operate with the same ultimate effect when subjected to identical conditions, and which would operate successfully when intermingled with each other in a train.

Such tests were conducted on a specially constructed air-brake testing track in the year 1894. Five companies responded with valves for the series of tests, of which the valves representing the Westinghouse and New York companies gave the best results. From the results obtained, the committee prepared a code of tests for triple valves, which code was soon after adopted by the Association as standard. As a result of this action, makers of air-brake apparatus endeavored to produce triple valves which would give results as specified in the code. This naturally led to interchangeable air-brake systems—one of the objects the committee hoped to attain. Many



MODERN AMERICAN HOPPER-BOTTOM GONDOLA CAR, WITH AIR BRAKE EQUIPMENT triple-valve tests have since been made, and the code has been changed from time to time to meet new conditions which have developed.

To-day there are mainly two air-brake systems in general use on steam railroads in this country, namely—the *Westinghouse* system and the *New York* system.

WESTINGHOUSE AIR-BRAKE SYSTEM

The principle on which the Westinghouse Air-Brake system operates, is, that if, after the system is charged with compressed air, a reduction is made in the brake-pipe pressure, the brake will be applied; and in order to release the brake, the brake-pipe pressure must be restored. It follows that if any accident occurs to the braking apparatus which reduces the pressure in the brake-pipe—such as the train parting or hose bursting—the brakes will at once be applied. In this respect, the Westinghouse Air-Brake system is automatic. The system is composed of the following principal parts:

1. The *steam-driven air-pump* located on the engine, which furnishes compressed air for the whole system.
2. The *main reservoir,* which is located some place about the engine or tender, and in which compressed air is stored at a pressure of 90 pounds.
3. The *engineer's brake-valve,* which is located in the cab, by means of which the flow of air from the main reservoir to the brake-pipe and from the brake-pipe to the atmosphere is regulated.
4. The *air-pressure gauge,* which is located in plain view of the engineer. and which contains two pointers, one red and one black. The black hand indicates the brake-pipe pressure; and the red hand, the main reservoir pressure.
5. The *pump-governor,* which regulates the flow of steam to the pump, shutting off the steam when the maximum pressure carried in the main reservoir is reached.
6. The *brake-pipe* which consists of a pipe under each car with flexible hose connection between cars, connecting all the triple valves with the engineer's brake-valve. This pipe has been, and is sometimes still, referred to as the *train line;* but as there are other train lines, such as the signal and steam lines, it has of late been referred to as the brake-pipe.
7. The *auxiliary reservoir* on each car, in which air is stored for use in applying the brake.
8. The *brake-cylinder* on each car, which contains a piston and rod. When air is admitted behind the piston, it causes it to move outward, and, by means of suitable connection to the foundation gear, applies the brake.
9. The *triple valve,* located under each car, the operation of which admits air from the brake-cylinder to the atmosphere, and recharges the auxiliary reservoir.
10. The *pressure-retaining valve,* which, when closed, will retain a pressure of 15 pounds in the brake-cylinder and thus prevent a complete release.

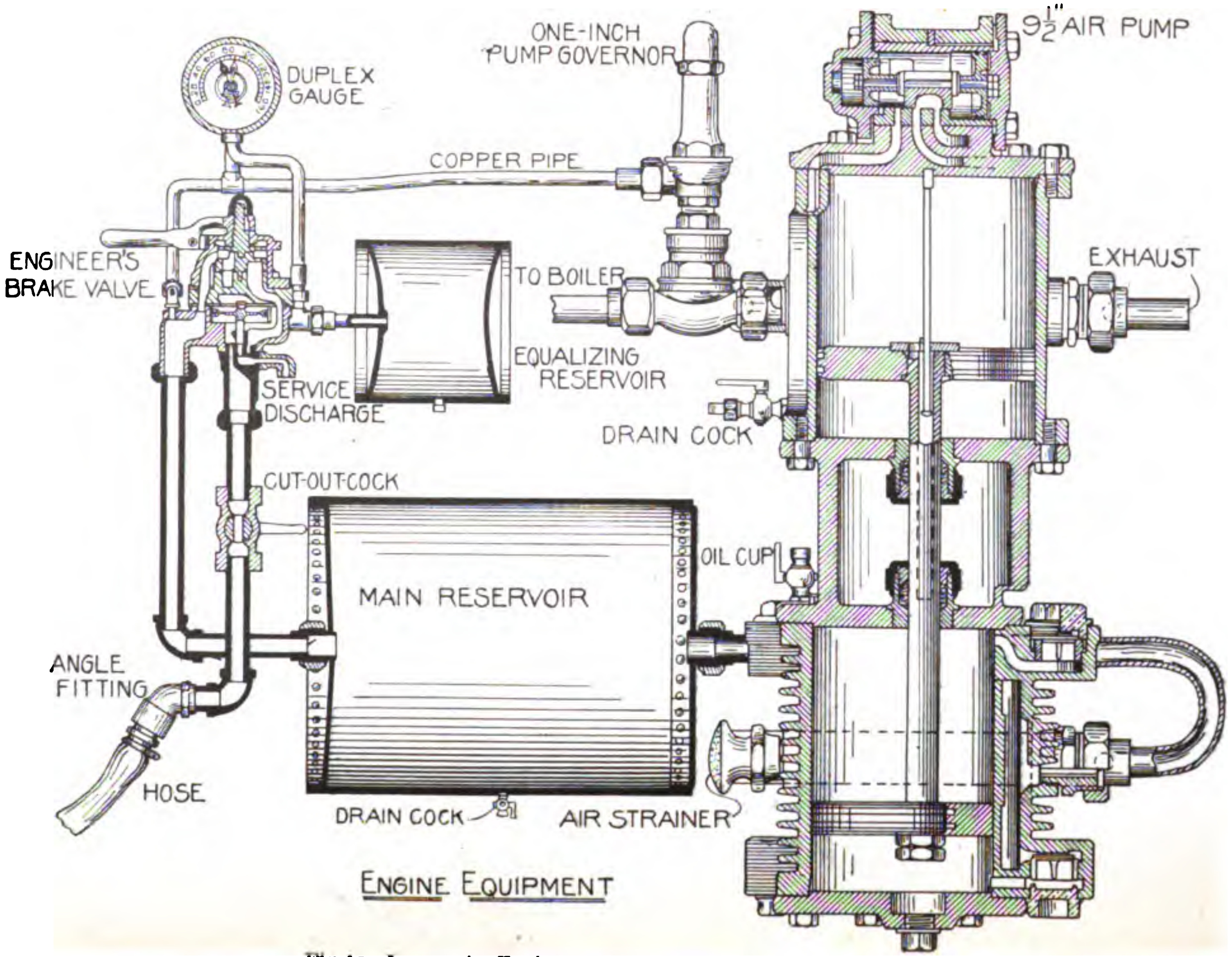


Fig. 1a. Locomotive Equipment, Westinghouse Air-Brake System.

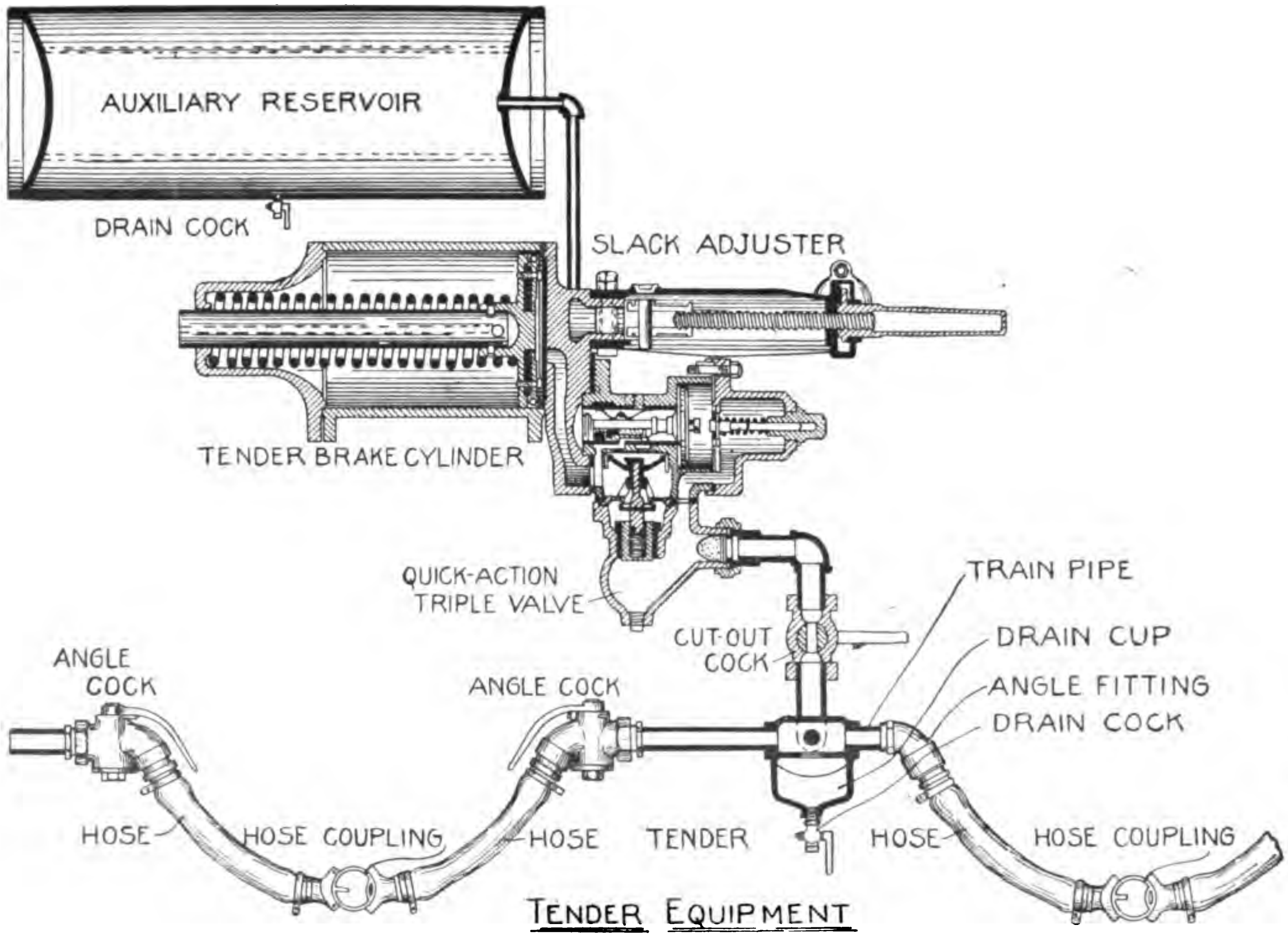


Fig. 1b. Tender Equipment, Westinghouse Air-Brake System.

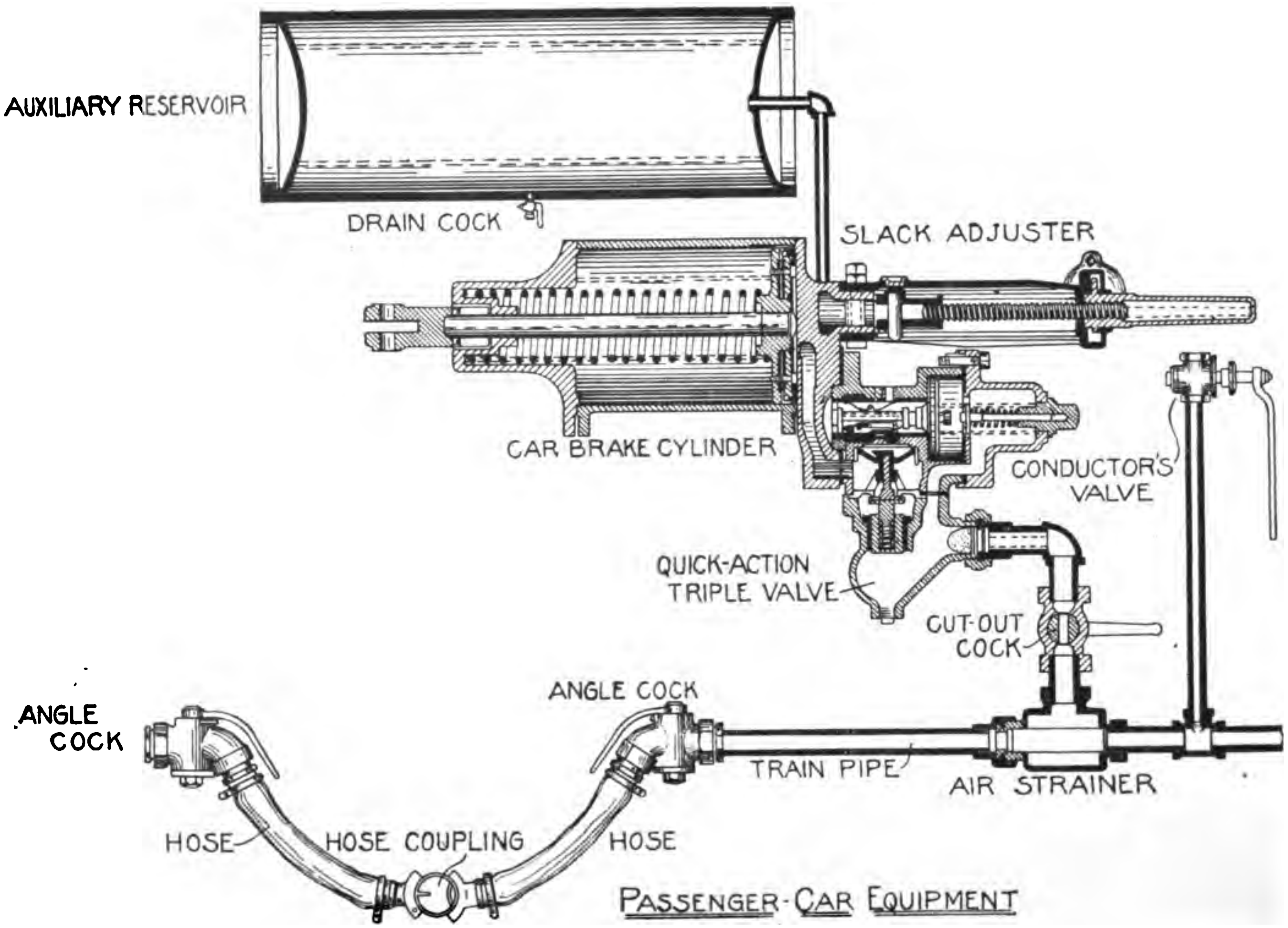


Fig. 1c. Passenger-Car Equipment, Westinghouse Air-Brake System.

The general arrangement of the Westinghouse air-brake system is shown in Fig. 1, (*a*, *b*, and *c*). This diagrammatically illustrates the arrangement and gives the names of the parts as found upon the locomotive, tender, and first car of a passenger train.

Operation of the Westinghouse Air-Brake. When the brakes are in operating condition, the pump-governor is set to maintain a pressure of 90 pounds in the main reservoir. This pressure is reduced by a valve attached to the engineer's brake-valve, which keeps the brake-pipe pressure at 70 pounds, when the engineer's brake-valve is in running position. The operation of the brake is controlled by the engineer's brake-valve, which has five fixed positions for its handle. These positions named in order, beginning from the left, are: *Release*, *running*, *lap*, *service*, and *emergency*.

When the engineer's brake-valve is in *running* position, a pressure of 70 pounds is maintained in the brake-pipe by means of the feed-valve. The brakes will release when the valve is in this position, but they will do so very slowly.

To make a *service* application of the brakes, the handle of the engineer's valve is placed in service position. In this position, the connection between the main reservoir and the brake-pipe, through the feed-valve, is closed. Air from the brake-pipe is allowed to escape to the atmosphere through ports in the valve. The brake-valve is left in this position only for a short time, when it is placed in lap position.

In the *lap* position, all working parts are closed and the brakes are held applied.

When it is desired to release the brake after either a service or an emergency application, the handle of the engineer's valve is placed in *release* position. In this position, direct connection is made between the main reservoir and the brake-pipe.

When it is necessary to make an *emergency* application, the handle of the engineer's brake-valve is placed in emergency position, and direct connection is made between the brake-pipe and the atmosphere. This causes a sudden reduction of pressure in the brake-pipe, and gives a higher pressure in the brake-cylinder than is obtained in service applications.

Westinghouse Nine and One-Half Inch Air-Pump. The nine and one-half-inch pump is shown in Figs. 2, 3, and 4. The pump consists of two cylinders. The lower (1) is the air-cylinder, and the upper (2) is the steam cylinder. The pistons of these cylinders are connected by the hollow rod (3). The air end is very simple, free air being drawn in at the valves (4), and discharged under pressure at the valves (5). The steam end is somewhat complicated in structure, but very simple in principle. The valve gear consists of two pistons (6) and (7), of unequal diameters, connected by the rod (8). This rod gives motion to a common D slide-valve (9) which admits steam above and below the main piston (10). The motion of the piston (6) and (7) is obtained by the slide-valve (11), Fig. 2, admitting and exhausting steam at the right of the piston (6). Steam enters the valve chamber *B* through the passage *A*. With the parts in the position shown in Figs. 2 and 4, steam from the chamber *B* passes down through the open port *C* below the piston (10), causing it to rise. The steam above the piston (10) passes out through the port *D* into the chamber *E* in the slide valve (9) through the exhaust port *F* to the atmosphere. The piston (10) continues to rise until the plate (12) strikes the upper shoulder on the rod (13) which raises the slide-valve (11). This allows the steam to pass from the chamber *B* through the port *H* around the slide valve (11) through the port *G* into the chamber *I*. In this position, the same pressure acts on both sides of the piston (6). Since the chamber *J* is always in communication with the exhaust passages through the port *K*, the pressure on the piston (7) is unbalanced. This causes all parts to move to the left. This movement opens the port *D*, permitting steam to force the piston (10) downward. At the same time, the port *C* is put in connection

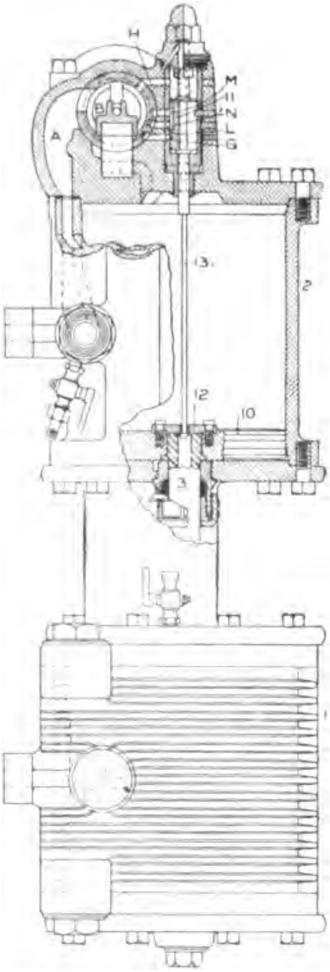


Fig. 2. Westinghouse 9½-Inch Air-Pump. End Section.

with the exhaust port *F* through the cavity *E* in the slide-valve (9). The piston (10) continues to fall until the plate (12) strikes the button on the lower end of the rod (13), drawing the valve (11) downward to the position shown in Fig. 2. This closes the port *G*, and connects the chamber *I* through the port *L*, the cavity *N*, and the port *M*, with the main exhaust *F*. This releases the pressure on the right of the piston (6). The pressure on the piston (6) now being greater than on the piston (7) will cause both to move to the right, thus completing the cycle.

Eight and One-Half Inch Cross-Compound. This pump is coming into use as a result of the growing demand for more air on long freight trains. Its capacity is about three and one-half times that of the 9½-inch pump above described. As illustrated in Fig. 5, this pump is of the duplex type, having two steam and two air cylinders arranged with the steam cylinders above and the air cylinders below. The high-pressure steam cylinder is 8½ inches in diameter; and the low-pressure, 14½ inches in diameter, both having a 12-inch stroke. The low-pressure air cylinder is 14½ inches in diameter, and is located under the high-pressure steam cylinder. The high-pressure air cylinder is under the low-pressure steam cylinder, and is 9 inches in diameter. The valve gear is located on the top head of the high-pressure steam cylinder, and is very similar to that of the 9½-inch pump already described. Figs. 6 and 7 show diagrammatically a cross-section through the pump. Fig. 6 is a diagram of the parts during an up-stroke of the high-pressure steam side, and Fig. 7 shows the down-stroke of the high-pressure steam side. The high-pressure steam piston is shown on the right, and the low-pressure on the left. The high-pressure steam piston, with its hollow rod, contains the reversing-valve rod, and operates the reversing valve in the same manner as that of the 9½-inch pump. This valve operates the main valve in the same manner as that described in the case of the 9½-inch pump. The main slide-valve controls the steam admission to, and the exhaust from, both the high- and low-pressure steam cylinders.

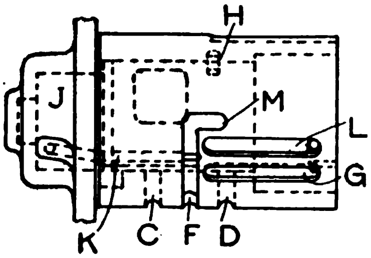
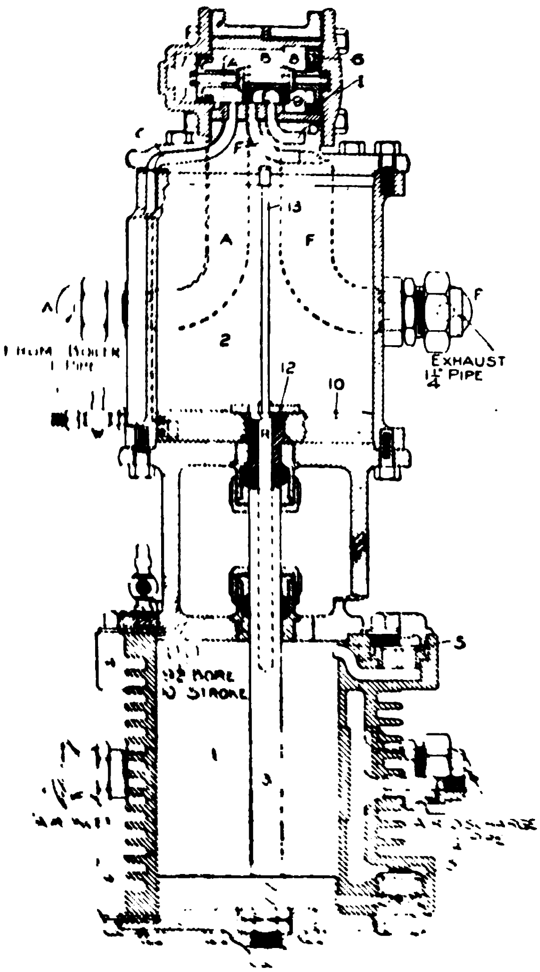


Fig. 3. Main Valve Bushing of Westinghouse 9½-Inch Air-Pump.

It is provided with an exhaust cavity, and in addition has four steam ports in its face. The two outer and one of the intermediate ports communicate with cored passages extending longitudinally in the valve, which serve to make the connection between the high- and low-



[illegible]

pressure [illegible] the expansion of steam from one to the [illegible] of steam [illegible]

[illegible]

shown in Figs. 6 and 7, lead to the upper and lower ends of the high-pressure steam cylinder. The first and third from the left lead to the upper and lower ends of the low-pressure steam cylinder; and the second, to the exhaust. By following the arrows in Figs. 6 and 7, the flow of air and steam through the pump can easily be traced.

The principle of compounding employed in this pump enables it to compress air much more economically than is possible with the simple pump.

Main Reservoir. The use of the main reservoir is for storing an abundant air-supply to be used in charging and releasing the brakes. A large reservoir is of great importance, especially in freight service, since it provides air for an immediate recharging of the auxiliary reservoirs without running the pump intermittently at high rates of speed. The main reservoir should have a capacity of not less than 24,000 cubic inches on passenger engines, and not less than 40,000 cubic inches on freight engines. The main reservoir is usually located somewhere on the engine; but sometimes it is placed on the tender, though the latter location necessitates two extra pipe connections between the engine and the tender, which is not good practice. A good practice is to divide the main reservoir, and place half on each side under the running-board. The air is then delivered to one side and taken out of the other, the two reservoirs being connected. This system has two decided advantages over others, one being that the air is cooled, thus causing the moisture to be collected in the reservoir. The other advantage is, that the distance between the inflow and out-take prevents much of the dirt and oil from being

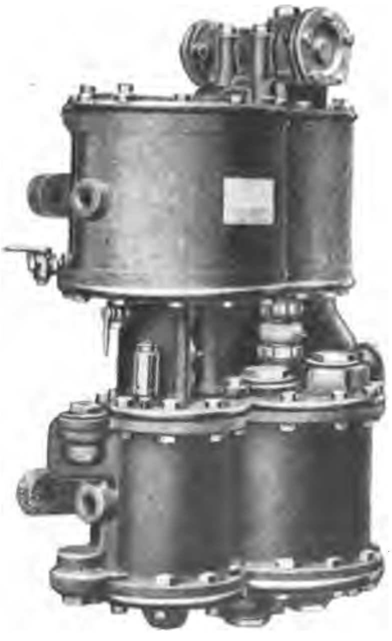


Fig. 5. Westinghouse 8½-Inch Cross-Compound Pump.

carried into the brake-pipe. The main reservoir should always be *drained* after each run.

Air-Pump Governor. The purpose of the governor is to cut off the steam supply to the pump when the desired main-reservoir pressure has been reached. Fig. 8 is a section through the governor. When the pump is in operation, steam enters the governor at *B*, passes the valve (2), and enters the pump through the pipe *C*. An air connection is made at *A* with the main reservoir. Main-reservoir air thus enters the chamber *D;* and as soon as this pressure on diaphragm (1) is sufficient to overcome the tension of the spring (3), the diaphragm (1) will be raised and will unseat pin valve (4). Air will then flow down into the chamber *E,* forcing the piston (5) downward, thus seating the valve (2) and shutting off the steam from the pump. When the air-pressure falls below that carried in the main reservoir, the spring (3) will force the diaphragm (1) down, and will seat the pin

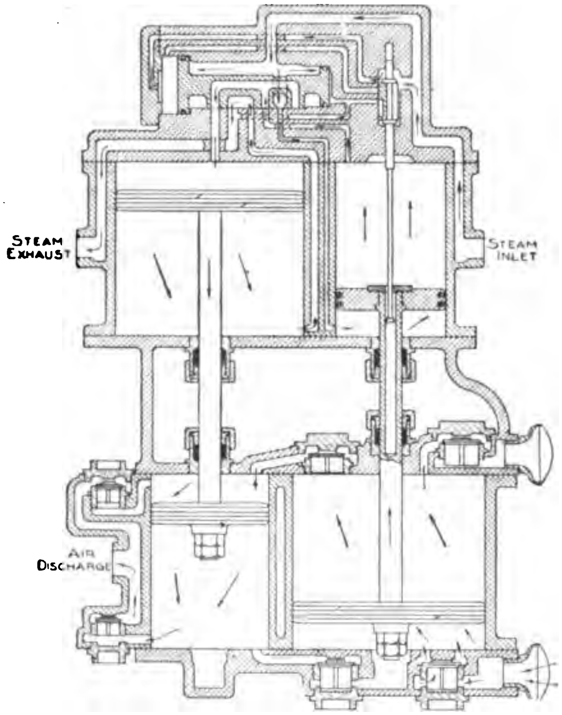


Fig. 6. Section of 8½-Inch Cross-Compound Pump, Up-Stroke, High-Pressure Steam Side.

valve (4). The air in the chamber *E* will now escape to the atmosphere through the small relief port *F*, and the spring (6) will open the valve (2), again admitting steam to the pump.

While the pin valve is unseated, there is a small escape of air to the atmosphere through the port *F*. This leakage, together with a leakage of steam through a small port in the valve (2), serves to keep the pump slowly operating and thus avoids trouble from condensation in the steam pipe.

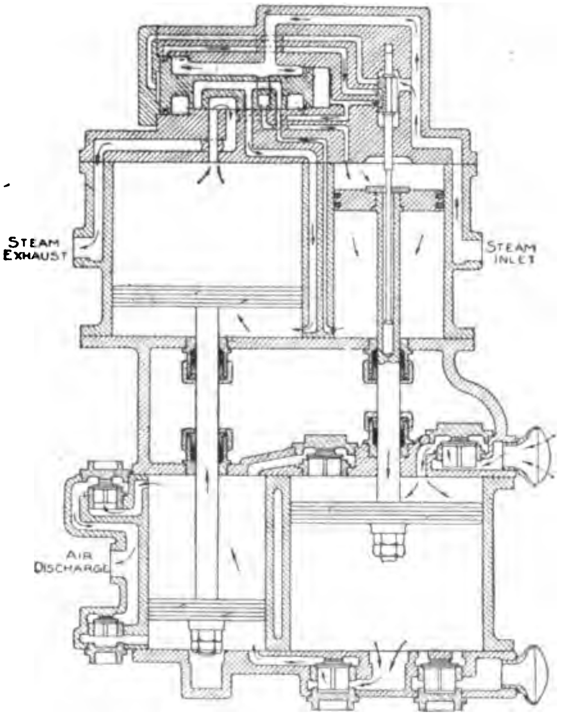


Fig. 7. Section of 8½-Inch Cross-Compound Pump, Down-Stroke, High-Pressure Steam Side.

Westinghouse Engineer's Brake-Valve. The construction of the engineer's brake-valve is illustrated in Figs. 9, 10, and 11. Fig. 9 is a section through the body, with the rotary valve removed, and shows the different positions of the handle. Figs. 10 and 11 are vertical sections of the entire valve taken at right angles to each other. The description of the operation of the valve is given in the order in which it is generally used when braking a train.

Running Position. The valve is shown in running position in Fig. 10. Main-reservoir air from the chamber *A* flows through the port *B* in the rotary valve (1) into the passage *C*, which conducts it to the feed-valve. (The course of the air through the feed-valve will be described later.) From the feed-valve, the air is conducted by the passages *D* and *E* to the chamber *F*, and from here to the brake-pipe. The cavity *G* in the rotary valve (1) connects the passage *E* with the port *H*, permitting air at brake-pipe pressure to enter the chamber *I* and flow through the passage *J* into the equalizing reservoir.

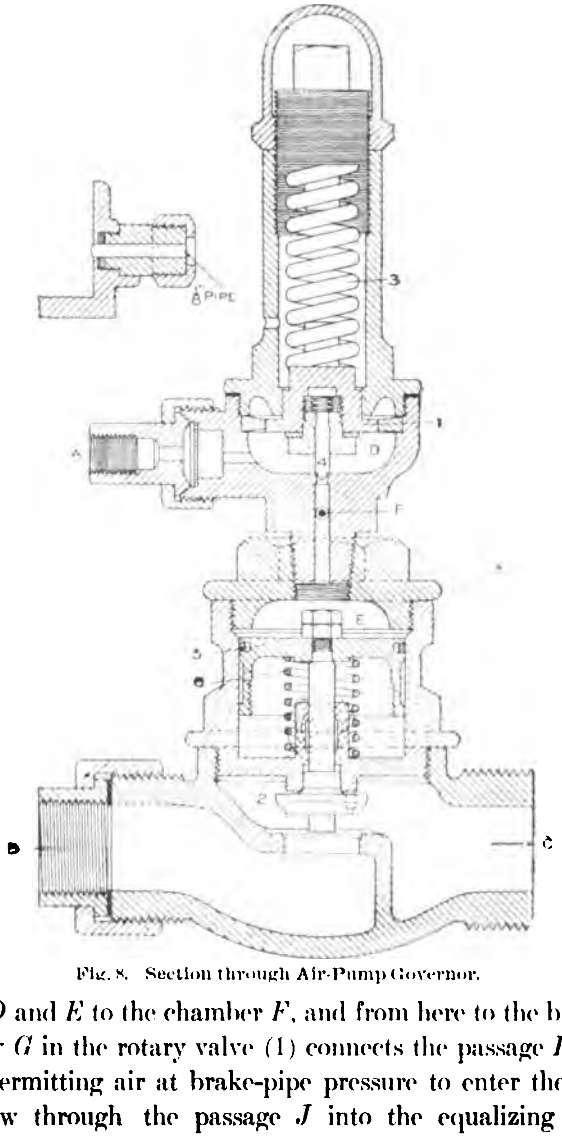


Fig. 8. Section through Air-Pump Governor.

Brake-pipe pressure now exists on both sides of the equalizing piston (2). Air continues to flow into the brake-pipe and equalizing reservoir until the pressure reaches 70 pounds. At this pressure, the feed-valve closes the passage leading from the main reservoir. In this position, the brake-pipe is kept charged to 70 pounds' pressure; 90 pounds' pressure is maintained in the main reservoir; and the entire system is ready for an application.

Service Position. When it is desired to reduce the speed of a train or to stop at a station, the handle of the engineer's brake-valve is placed in *service* position until the brake-pipe reduction causes enough air to enter the brake-cylinders to produce the desired result. When the brake-pipe reduction is sufficient, the handle of the valve is placed in *lap* position as described below. In service position a groove in the rotary valve (1) connects the port *K* with the groove *L*, both of which are in the valve-seat. This permits air from the chamber *I* and the equalizing reservoir to discharge through the passage *M* to the atmosphere, thus reducing the pressure on the top side of the equalizing piston (2). Brake-pipe pressure, being greater than the pressure on the top side of the equalizing piston (2), forces it upward, opening the attached discharge valve, and permitting air to flow from the brake-pipe through the port *N* and the passage *O* to the atmosphere. When the pressure in the equalizing reservoir is reduced the desired amount, the handle of the engineer's brake-valve

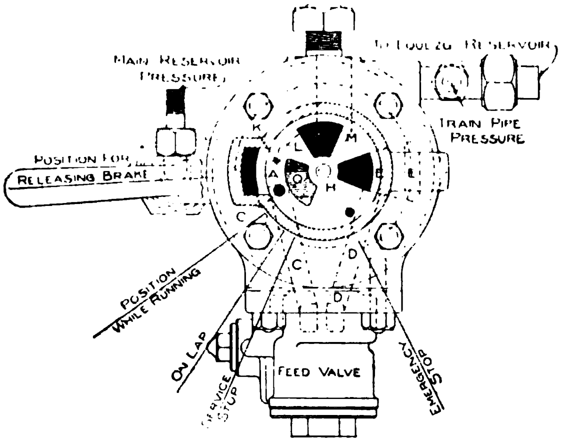


Fig. 9. Section through Engineer's Brake-Valve. Rotary Valve Removed, and Different Positions of Handle Shown.

is moved to lap position. Air continues to discharge through the above-mentioned passages until the pressure in the brake-pipe has reduced slightly below that in the equalizing reservoir and chamber *I*; then the greater pressure acting on the top of the piston (2) causes it automatically to close the discharge valve. When the piston (2) closes the discharge valve, the pressure in the brake-pipe and equalizing reservoir is about the same.

The equalizing reservoir is 10 inches in diameter and 12 inches long. Its purpose is to increase the volume of air so that the pressure in the chamber *I* will not drop too rapidly when the handle is placed in service position. If a reduction of pressure be made in the equalizing reservoir, and the handle placed in lap position, air will exhaust from the brake-pipe until its pressure is the same as that in the equalizing reservoir.

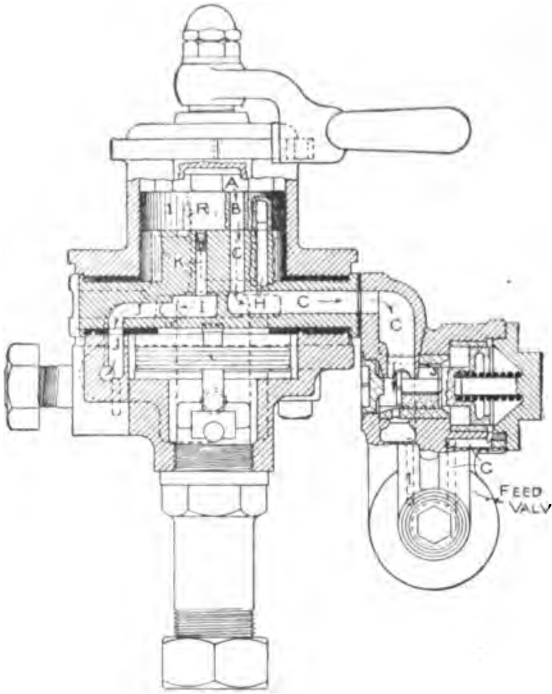


Fig. 10. Engineer's Brake-Valve in Running Position.

Lap Position. This position is the one in which the valve handle is placed after a light reduction has been made in the brake-pipe.

It remains in this position, holding the brake applied until a further brake-pipe reduction is desired or until the brake is released. In this position, all ports are operatively closed. No air can enter the brake-pipe from the main reservoir, and no air from the brake-pipe can escape to the atmosphere.

Emergency Position. In case of an emergency, the handle of the brake-valve is moved to the extreme right. In this position, direct-application-and-exhaust port M is connected with direct-application-and-supply port E by the cavity G in the rotary valve (1). This establishes direct communication between the brake-pipe and the atmosphere, and a sudden reduction of pressure occurs in the brake-pipe. This causes all brakes to apply very quickly with full braking pressure.

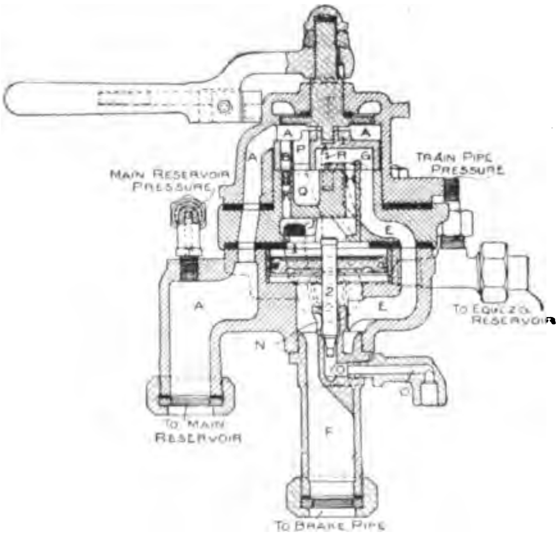


Fig. 11. Engineer's Brake-Valve in Release Position.

Release Position. The parts of the valve are shown in release position in Fig. 11. The purpose of this position is to provide large ports through which air can flow from the main reservoir to the brake-pipe and quickly recharge the system and release the brakes. Air from the main reservoir flows from the chamber A, through the port P, the cavities Q and G, into the passage E and to the brake-pipe. The ports H and K both conduct air to the chamber I, and the equalizing reservoir is charged through the passage *J* to the same pressure as exists in the brake-pipe.

The brake-valve handle should not remain in this position too long, as there is danger of overcharging the brake-pipe and the auxiliary reservoirs. The *warning port R* in the rotary valve (1) permits a small amount of air to escape from the chamber *A* to the exhaust passage *M*, making a noise which notifies the engineer that the brake-valve is still in release position.

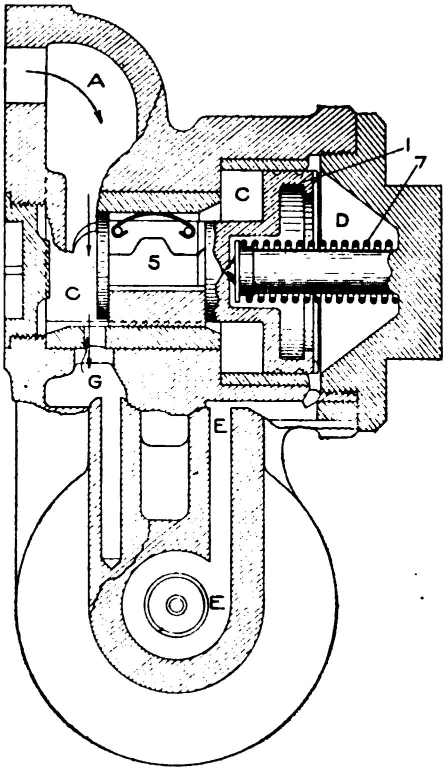
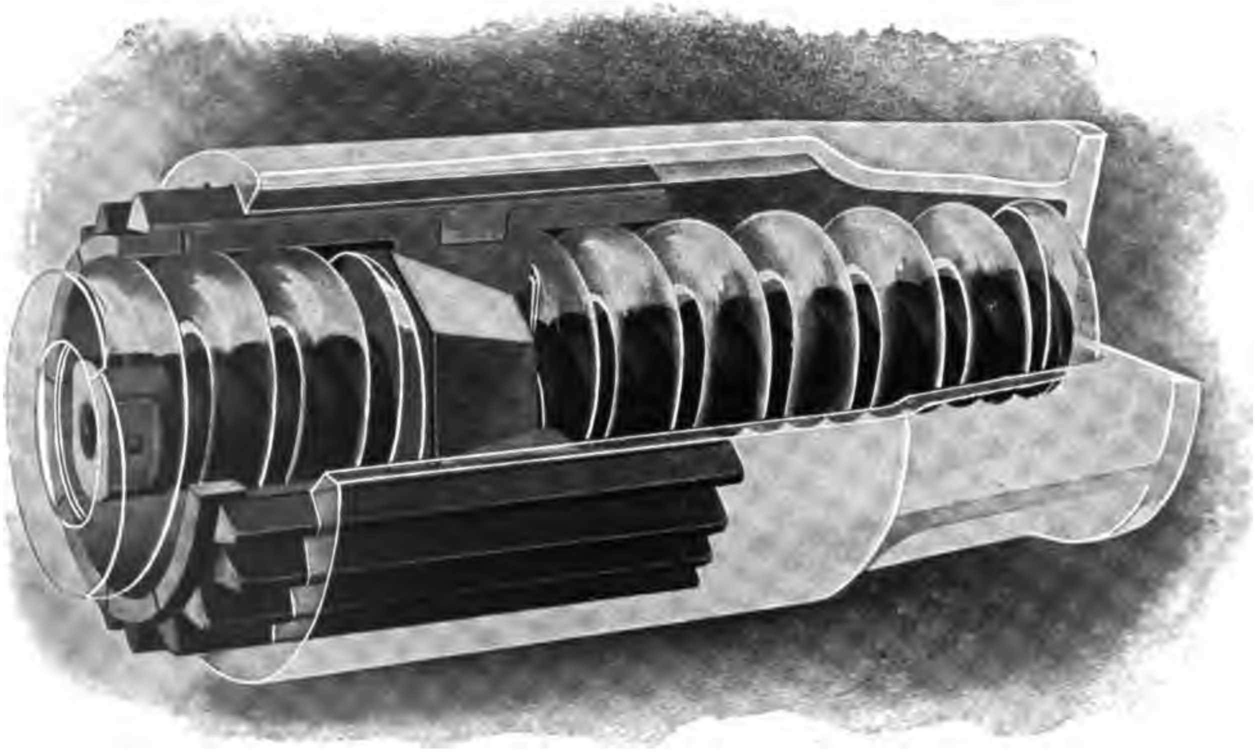


Fig. 12. Central Section through Supply-Valve Case and Governing Device of Slide-Valve Feed-Valve.

Slide-Valve Feed-Valve. The purpose of the feed-valve is to maintain a predetermined pressure in the brake-pipe while the engineer's valve is in running position. Figs. 12 and 13 illustrate the slide-valve feed-valve. Fig. 12 is a central section through the supply-valve case and governing device. Fig. 13 is a transverse section through the supply-valve case, and a central section through the regulating valve and spring-box. The ports *A* and *B* register with the ports in the brake-valve. The port *A* is in communication through the engineer's valve with the main reservoir, when the engineer's valve is in running position. Air enters the feed-valve at *A*, and has at all times free communication with the chamber *C*. The chamber *C* is separated from the chamber *D* by the supply piston (1). Connection is made between the chamber *D* and the brake-pipe through the passage *E*, the regulating valve (2), the chamber *F*, and the port *B*. The regulating valve (2) is normally held open by the tension of the spring (3) upon the diaphragm



TRANSPARENT INTERIOR VIEW OF WESTINGHOUSE FRICTION DRAFT GEAR.

Application—The large "preliminary spring" at the left absorbs ordinary stresses and forces the friction strips against the friction cylinder. The small spring gives additional pressure on the wedge. When both springs become compressed, the friction strips are moved with increasing resistance, absorbing a pressure of over 150,000 lbs. before completion of stroke.

Release—The small spring at the left releases the wedge and the large spring returns friction strips to normal position, practically without reco"

(4). When the valve (2) is open, the chamber *D* has brake-pipe pressure acting upon it as described above. When the handle of the engineer's brake-valve is placed in running position, main-reservoir air enters the chamber *C* and forces the piston (1) to the right, as shown in Fig. 12. This draws the slide valve (5) to the right, uncovers the port *G*, and direct connection is made between the main reservoir and the brake-pipe through the chamber *C*, the port *G*, and the passage *B*.

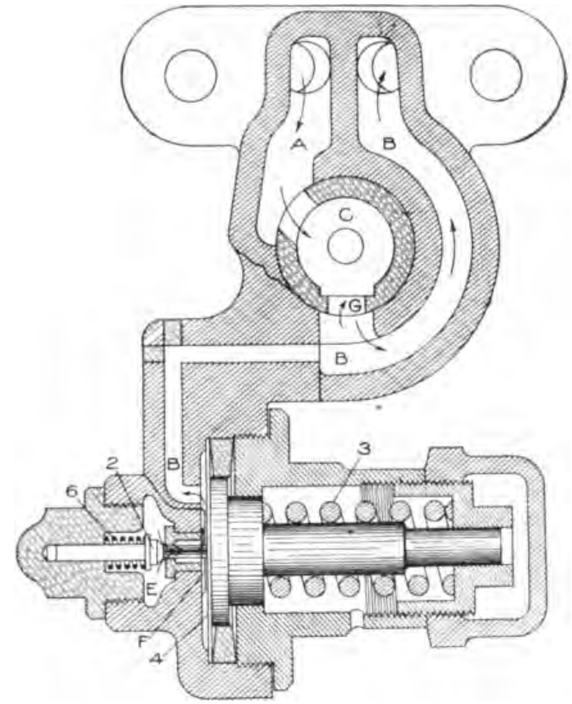


Fig. 13. Transverse Section through Supply-Valve Case, and Central Section through Regulating Valve and Spring-Box of Slide-Valve Feed-Valve.

Air now flowing from the main reservoir will raise the brake-pipe pressure until the pressure in the chamber *F* is sufficient to overcome the tension of the regulating spring (3). This requires 70 pounds in the ordinary equipment. The spring (6) will now seat the regulating valve (2), and cut off communication between the brake-pipe and the chamber *D*. The pressure in the chambers *C* and *D* will then equalize through leakage past the piston (1), when the spring (7) will move the piston (1) and the slide-valve (5) to the left, closing the

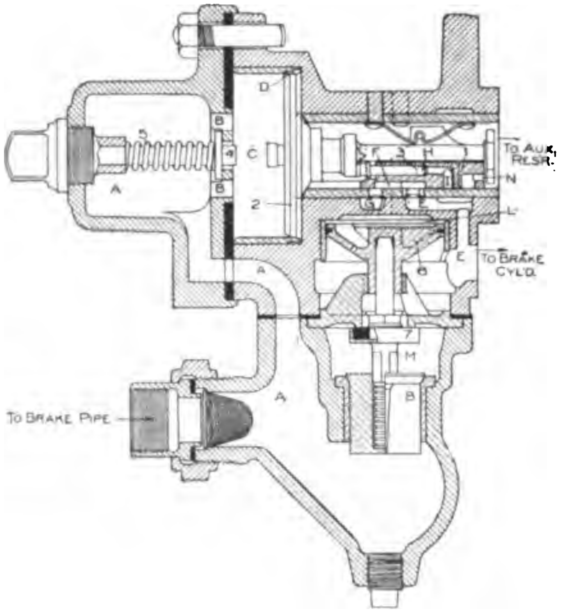


Fig. 14. Quick-Action Triple Valve, Release Position.

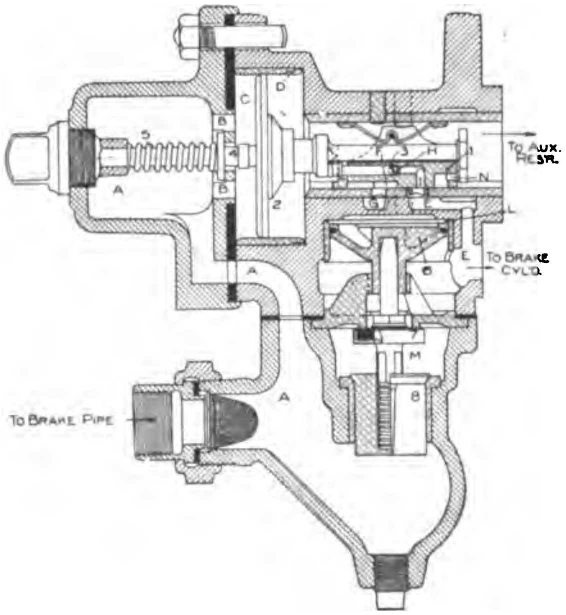


Fig. 15. Quick-Action Triple Valve, Service Application.

port *G* and shutting off communication between the main reservoir and the brake-pipe. A subsequent reduction of brake-pipe pressure will cause the regulating spring (3) to unseat the valve (2), and the accumulated pressure in the chamber *D* will discharge to the brake-pipe. The pressure in the chamber *C* being greater than that in the chamber *D*, the piston (1) will move to the right and uncover port *G*, allowing the brake-pipe to be recharged.

Quick-Action Triple Valve. The quick-action triple valve is shown in its four positions by Figs. 14, 15, 16, and 17. The principal parts are numbered as follows: (1) Slide valve, (2) main piston, (3) graduating valve, (4) graduating stem, (5) graduating spring, (6) emergency piston, (7) emergency valve, and (8) check-valve.

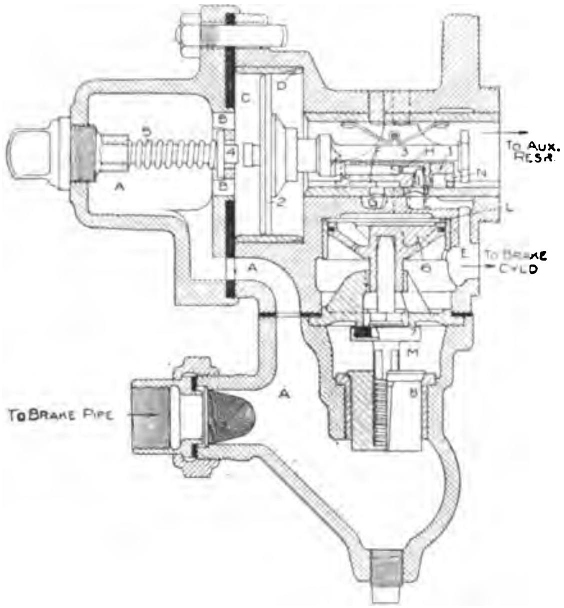


Fig. 16. Quick-Action Triple Valve, Lap Position.

Charging or Release. Fig. 14 shows the position of the triple valve when the auxiliary reservoir is being charged and the brake is being released. Air enters the triple valve at the point marked "To Brake-Pipe," and follows the passage *A* through the port *B* into the chamber *C*, through the feed-groove *D*, over the slide-valve (1), to the auxiliary reservoir. This flow of air will continue until the pressure in the auxiliary reservoir is equal to the pressure in the brake-pipe. This pressure is 70 pounds in the ordinary equipment. At the same time, air from the brake-cylinder enters the triple valve at the point marked "To Brake-Cyl'd," and passes through the port *E*, through the cavity *F* in the slide-valve (1) (see Fig. 18), and into the exhaust port *G* to the atmosphere.

Service Position. Fig. 15 shows the position of the triple valve during a service application. A reduction of about 5 pounds in the brake-pipe reduces the pressure in the chamber *C*, and causes the piston (2) to move to the left until it strikes the graduating stem (4). This closes the feed-groove *D* and opens the graduating valve (3).

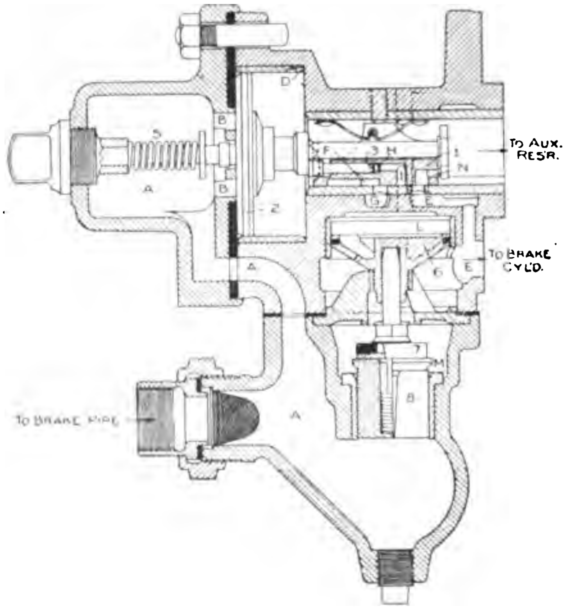


Fig. 17. Quick-Action Triple Valve, Emergency Application.

Auxiliary-reservoir air now flows into the brake-cylinder through the port *H*, passing the graduating valve (3) into the port *I*, which registers with the port *E*.

Lap Position. As soon as the pressure on the auxiliary-reservoir side of the piston (2) has fallen below the brake-pipe pressure, the piston (2) will move to the right and seat the graduating valve (3). This is known as *lap position*, and is shown in Fig. 16. The flow of air from the auxiliary reservoir to the brake-cylinder now ceases. Since the difference in pressure on the two sides of the piston (2) is not sufficient to overcome the frictional resistance of the slide-valve (1), all ports remain in the position shown until another reduction in the brake-pipe is made or until the brake is released. A service reduction of 25 pounds in the brake-pipe will equalize the pressure in the auxiliary reservoir and brake-cylinder at about 50 pounds, this being the maximum pressure obtainable in a service application.

Emergency Application. A sudden reduction of air in the brake-pipe will cause the piston (2) to move to the left with such force that its impingement against the graduating stem (4) will compress the graduating spring (5), as shown in Fig. 17. In this position of the parts, a diagonal slot *J* in the slide valve (1), Fig. 18, registers with the port *K*, which opens into the chamber *L* above the emergency piston (6). This permits auxiliary-reservoir air to act on the piston (6), forcing it down, unseating the emergency valve (7), and allowing the air-pressure in the cavity *M* to enter the brake-cylinder. Brake-pipe pressure then lifts the check-valve (8), and air rushes into the brake-cylinder. At the same time, the auxiliary-reservoir air has a direct passage into the brake-cylinder through the port *N*, which registers with the port *E*. As the opening through the check-valve (8) and the emergency valve (7) is comparatively large, the brake-pipe discharges into the brake-cylinder very rapidly. This causes a quick reduction of pressure in the brake-pipe and affects the next triple in the train, causing it to act in the manner just described. Each triple valve in its turn is affected by the sudden drop in brake-pipe pressure, so that a full emergency application in a 50-car train can be made in about three seconds. The release from an emergency application is made in the same way as the release from a service application. In an emergency application, the pressure in the brake-cylinder rises to about 60 pounds, being about 10 pounds higher than that obtained in a full service application.

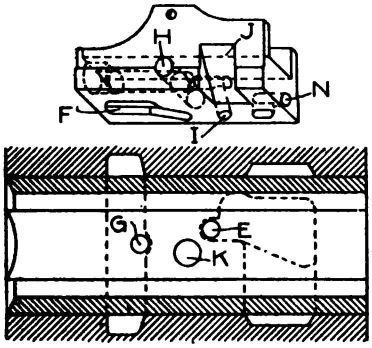


Fig. 18. Slide-Valve and Seat of Quick-Action Triple Valve.

Plain Triple Valve. Fig. 19 shows a section of the plain triple valve. This valve is like the quick-action triple valve, except that the slide-valve (3) and the axis of the main piston (2) are vertical instead of horizontal, and the emergency valve mechanism is omitted. In a service application, the operation of the plain triple is exactly the same as that of the quick-action triple valve, as already described.

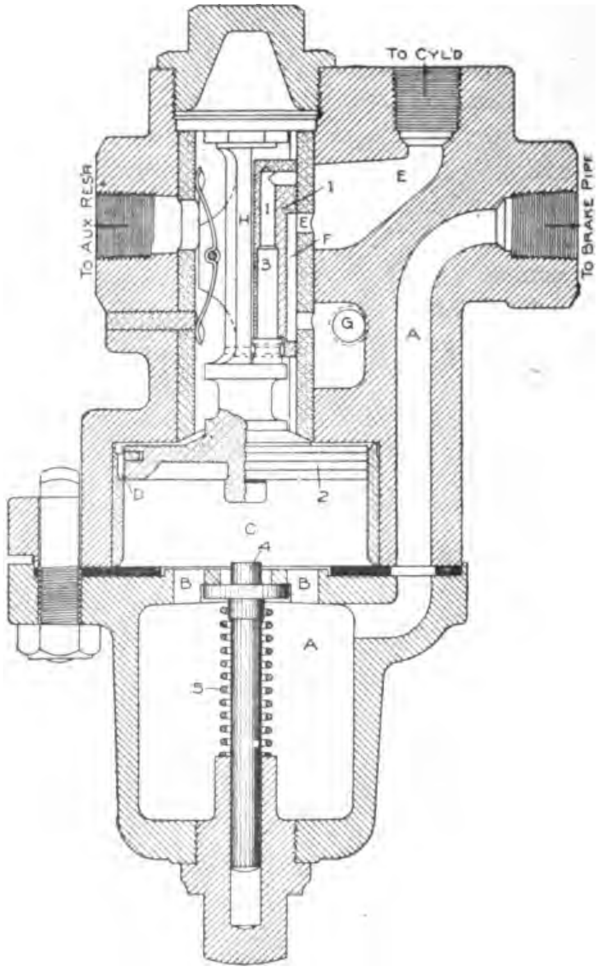


Fig. 19. Section of Plain Triple Valve.

When a sudden reduction of air is made in the brake-pipe, the piston (2) strikes the graduating stem (4), compresses the spring (5), and moves to its extreme lower position. The upper edge of the slide-valve (1) is now below the lower edge of the port *E*, and a direct communication between the auxiliary reservoir and the brake-cylinder is made. This will cause a quick application of the brake; but the final pressure in the brake-cylinder is no greater than if a full service application were made.

The plain triple valve is used largely on the tender and locomotive equipment, but is gradually being replaced by the quick-action triple.

Combined Freight-Car Cylinder, Reservoir, and Triple Valve. Fig. 20 shows the combined freight-car cylinder and reservoir, which is the usual form of equipment employed on freight-cars. Referring to Fig. 20, (1) is the quick-action triple valve; (2) is the auxiliary reservoir, which is simply a hollow cast-iron shell for the purpose of storing air for use in the brake-cylinder upon the same car; (3) is a release valve usually placed above the auxiliary reservoir for the purpose of releasing the brake in case of necessity; (4) is a pipe connecting the triple valve with the brake-cylinder; (5) is the brake-cylinder; (6) is the piston; (7) is the packing leather, which is pressed against the cylinder to prevent air from leaking past the piston; (8) is the follower plate that holds the leather to the piston; (9) is the spring expander, which presses the leather out against the cylinder wall; and (10) is a release spring which brings the piston back to the position shown after the air is exhausted from the cylinder. A rod extends from the valve (3) to either side of the car. If either rod is pulled, the pressure in the auxiliary reservoir will be exhausted and thus will release the brake. There is a small groove called the leakage groove, shown by dotted lines at *A*. This groove permits any small leaks of air which may enter the cylinder, to pass around the piston (6), and thus prevents its being moved outward and setting the brake.

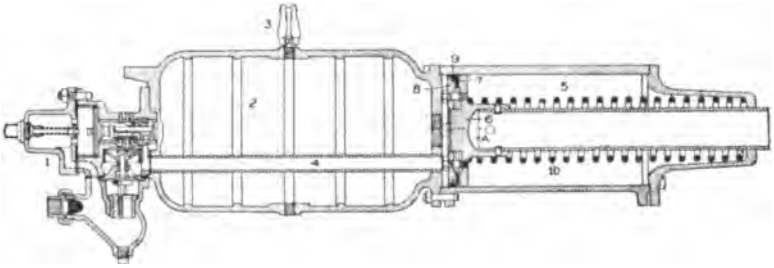


Fig. 20. Combined Freight-Car Cylinder, Reservoir, and Triple Valve.

The movement of the piston (6) should be such that the pressure in the auxiliary reservoir and brake-cylinder will equalize at 50 pounds in a full service application. To secure this pressure, the stroke of the piston must be about 8 inches. If the brake is applied when the car is not in motion, the stroke of the piston is called the *standing travel;* when in motion, it is called the *running travel.* Because of the slack in loose fitting parts, shoes pulling down on the wheels, etc., the *running travel* is about 1½ inches greater than the *standing travel.* For this reason, the brake rigging must be adjusted to give a piston travel of about 6½ inches when the car is not in motion. The brake-cylinder commonly used in freight-car equipment is 8 inches in diameter. When a larger cylinder is used, the auxiliary reservoir must be increased proportionally.

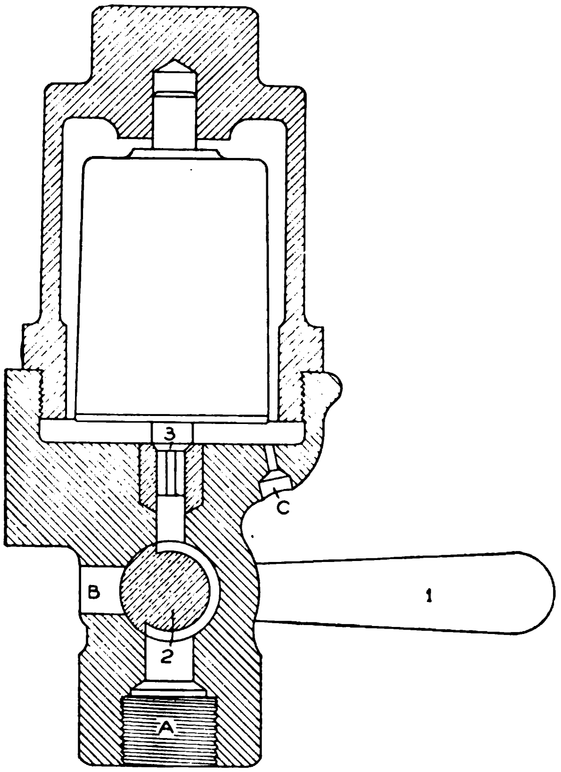


Fig. 21. Section of Pressure-Retaining Valve.

Pressure-Retaining Valve. Fig. 21 shows a section through this valve. A pipe is connected at *A* which comes from the exhaust port of the triple valve. When the valve handle (1) is down, the exhaust from the triple valve enters at *A*, passes the valve (2), and out at the port *B*. If the handle (1) is turned horizontally, as shown in Fig. 21, the air from the triple valve flows around the valve (2), lifting the weighted valve (3), and passes to the atmosphere through the port *C*. A pressure of over 15 pounds will raise the weighted valve (3). When the brake-cylinder pressure has become reduced to 15 pounds, the weighted-valve (3) seats, and the remaining 15 pounds pressure is retained in the brake-cylinder until the handle (1) is turned down. Pressure-retaining valves are used mostly on freight-cars; but some roads that have long, heavy grades use them on passenger cars also. These valves should be so located that they can be reached while the train is in motion. The usual location on freight-cars is at the end of the car, just under the foot-board.

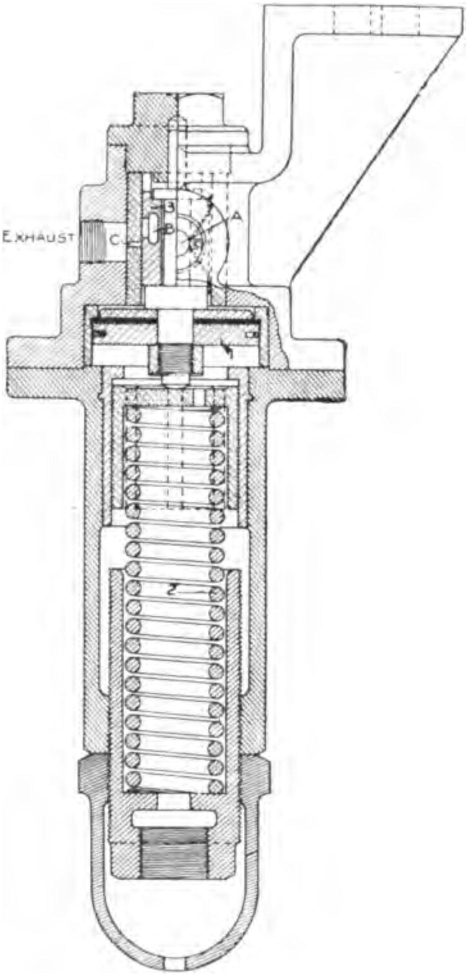


Fig. 22. Section of Automatic Reducing Valve.

High-Speed Brake. It has been known for several years that as the speed of the train is increased, the maximum brake-shoe pressure may also be increased without danger of skidding the wheels. That is, a train going at a speed of 80 miles an hour would require a much greater brake-shoe pressure to skid the wheels than a train going 5 miles an hour. This fact has been taken advantage of in the design of the high-speed brake. Instead of carrying a brake-pipe pressure of 70 pounds when the high-speed brake is in operation, 110 pounds is carried. When a full service application is made, 85 pounds pressure is obtained in the brake-cylinder. If this pressure were allowed to continue in the brake-cylinder until the train stopped, there would be danger of skidding the wheels. In order to prevent this, a valve known as the *automatic reducing valve* is used. This valve is shown in Figs. 22 and 23. The chamber *A* above the piston (1), Fig. 22, has at all times communication with the brake-cylinder by means of a pipe connection. When the pressure in the brake-cylinder is 60 pounds or less, the parts of the valve are in the position shown. If, during a heavy service application, the pressure in the brake-cylinder becomes greater than 60 pounds, its action on piston (1) will be sufficient to overcome the tension in the spring (2); and piston (1), together with the slide-valve (3), will move downward until the port *C* registers with the triangular port *B*, which is always in communication with the chamber *A*. Air from the brake-cylinder now escapes through chamber *A* and ports *B* and *C* to the atmosphere. This exhaust of air will continue until the brake-cylinder pressure is reduced to 60 pounds. The spring (2) then raises the piston (1), causing the slide-valve (3) to close the exhaust port *C*. In the operation just described, the greatest width of the triangular port *B* is exposed to the port *C*. These ports are so proportioned that in this particular position, the surplus air is discharged from the brake-cylinder as rapidly as it is admitted through the service application port of the triple valve.

In an emergency application, the violent admission of air into the brake-cylinder so suddenly increases the pressure that the piston (1) is forced to the lower end of its stroke. In this position, only the apex of the triangular port *B* in the slide-valve (3) registers with the port *C*, and a comparatively slow discharge of brake-cylinder air-pressure takes place while the train is at its highest speed; but the area of the opening of the port *B* gradually increases as the pressure decreases, until the pressure in the brake-cylinder is 60 pounds, after which time the port *C* is closed as in a service application.

The high-speed equipment is used principally on fast passenger trains. Fig. 23 shows the general arrangement under a passenger car of the auxiliary reservoir, brake-cylinder, triple valve, high-speed reducing valve, and pipe connections. The arrangement of the brake-cylinder and the auxiliary reservoir is different from that used on freight-cars, in that they are separate, and the triple valve is bolted to the brake-cylinder instead of to the auxiliary reservoir. On a locomotive used in handling both the high-speed and standard equipments, the engineer's brake-valve is fitted with two feed-valves; and the air-pump, with a duplex governor. One feed-valve is adjusted for 70 pounds, and the other for 110 pounds. One pump-governor is adjusted to maintain a pressure of 90 pounds in the main reservoir, and the other a pressure of 130 pounds.

The equipment on the locomotive may be changed from the standard to the high-speed by closing a cut-out cock in the pipe leading to the 90-pound pump-governor, and changing the feed-valve handle so that the 110-pound feed-valve is operative instead of the 70-pound feed-valve.

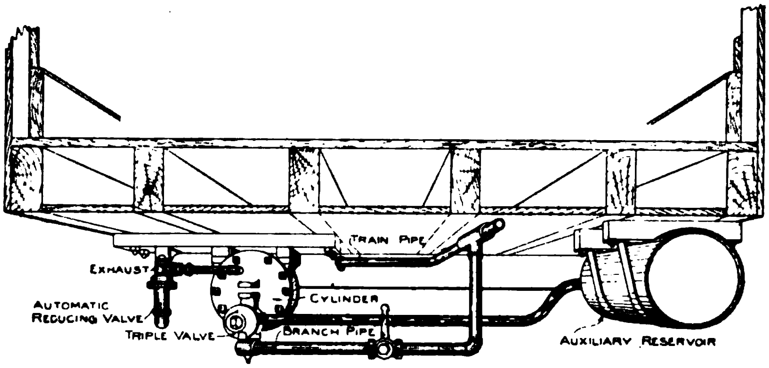


Fig. 23. Automatic Reducing Valve Applied to Car.

WESTINGHOUSE "E T" LOCOMOTIVE BRAKE EQUIPMENT

In a paper read before the 1906 meeting of the Air-Brake Association, Mr. F. H. Parke stated that the possible braking power of a single modern locomotive was over 10 per cent of a 50-car freight train, 12 per cent of a 12-car Pullman train, 25 per cent of a 10-car passenger train, and 35 per cent of a 6-car passenger train. These figures show that the brake equipment of the locomotive should receive special attention, and that the brake equipment commonly used on locomotives should be improved.

The first step taken in this direction was the development of the combined automatic and straight-air equipment for locomotives. This system provided a means for applying and releasing the brakes on the cars in the train. It greatly increased the control of the engine in switching and in handling the slack in long freight trains, but it had many undesirable features. It was greatly simplified and improved by the invention of the so-called "E T" locomotive brake equipment.

The "E T" equipment possesses all the advantages of the combined automatic and straight-air equipment, and several additional ones which are necessary to give satisfactory results in braking long trains. It can be applied to any locomotive without change or modification of any of its parts, and the locomotive so equipped can be used for any class of service. The Westinghouse Company makes the following claims for the "E T" equipment:

1. "The locomotive brakes may be controlled with or independently of the train brakes, and this without regard to the position of the locomotive in the train, whether coupled to another, as in double heading, or used as a helper and assigned to any position in the train.

2. "They may be applied with any desired pressure between the minimum and the maximum attainable; and this pressure will be automatically maintained in the locomotive brake-cylinders, regardless of leakage and variation in piston travel—undesirable though these defects are—until released by the brake-valve.

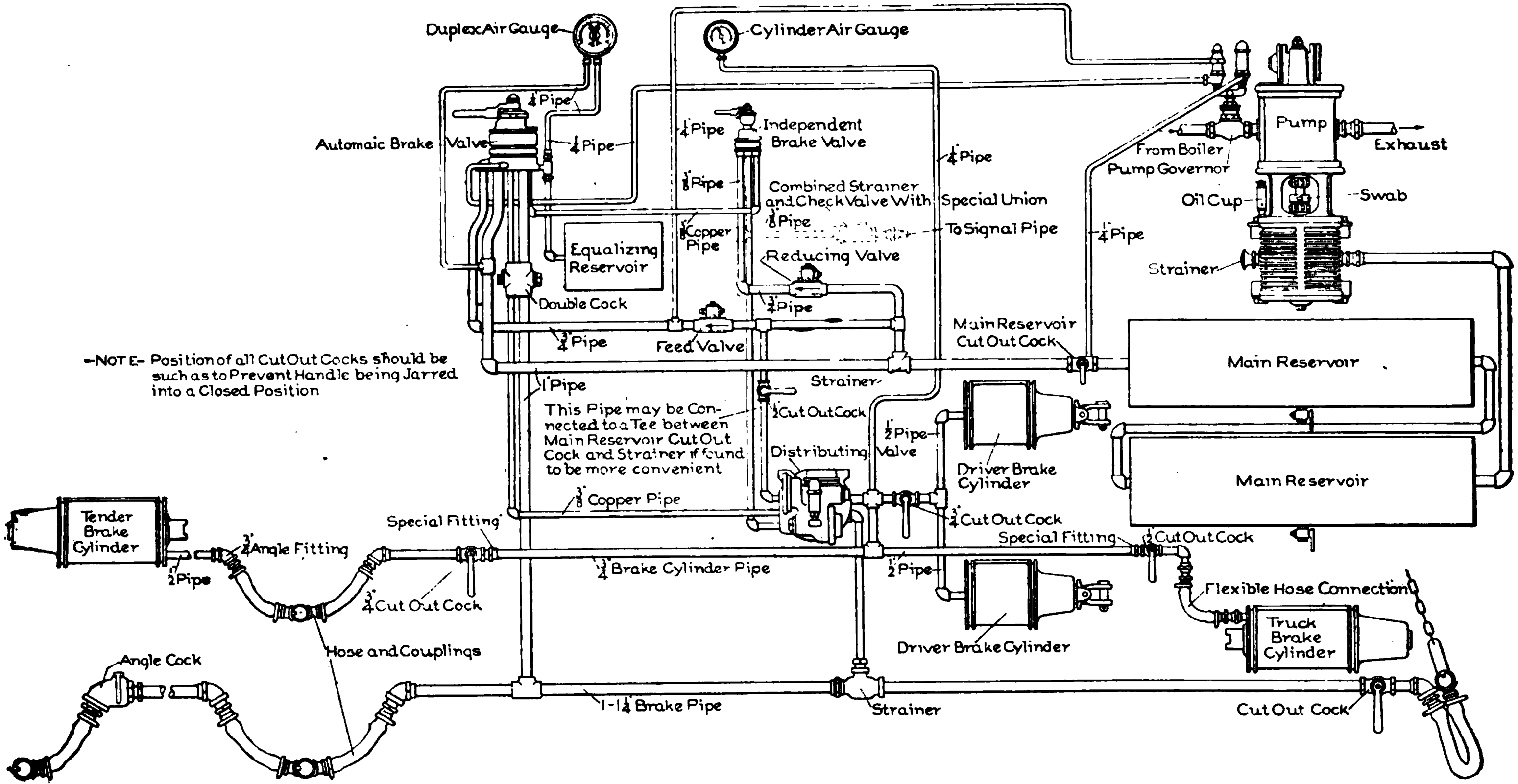
3. "They will remain applied when the engineer places the automatic brake-valve handle in full release, then in lap position preparatory to making the second application in a two-application stop, thus making a more uniform stop and requiring a lighter second application.

4. "They can be perfectly graduated on or off, either in the automatic or in the independent application; hence, in all kinds of service, the train may be handled without shock or danger of parting; and in passenger service especially, smooth and accurate stops can be made with greater ease than was heretofore possible."

Fig. 24 gives the names of all parts used in the equipment, and shows the scheme and sizes of piping. The parts not to be found in the quick-action automatic equipment as commonly installed on the locomotive, are as follows:

1. A *duplex pump-governor.*

2. A *distributing valve,* and small double-chamber reservoir to which it is attached. This valve performs the functions of triple valve, auxiliary reservoir, double check-valve, and high-speed reducing valve on the locomotive.



–NOTE– Position of all Cut Out Cocks should be such as to Prevent Handle being Jarred into a Closed Position

This Pipe may be Connected to a Tee between Main Reservoir Cut Out Cock and Strainer if found to be more convenient

Fig. 24. Piping Diagram of Westinghouse 'ET' Equipment.

3. *Two brake-valves*, one of which is automatic and operates both the train and locomotive brakes; the other an independent valve operating the locomotive brakes only.

4. A *feed-valve*, located in the reservoir pipe to regulate the brake-pipe pressure.

5. A *reducing valve*, which reduces the main-reservoir pressure for the independent brake-valve and for the air-signal system when used.

6. A *single-pointer gauge* to indicate the locomotive brake-cylinder pressure.

Manipulation. The instructions for operating the "ET" equipment are very similar to those given for the combined automatic and straight-air equipment. The automatic brake-valve has six fixed positions for its handle, while the independent brake-valve has but five. The positions for the automatic brake-valve are: *Release, running, holding* (driver brake), *lap, service,* and *emergency;* and those for the independent brake-valve are: *Release, running, lap, slow application,* and *quick application.*

The handles of both brake-valves should be kept in running position when not in use.

To make a service application on both locomotive and train brakes, move the handle of the automatic brake-valve to service position long enough to secure the required brake-pipe reduction; then move the handle back to lap position. All brakes will remain applied as long as the valve remains in this position.

The train brakes may be released by moving the handle of the automatic brake-valve to release position. When the valve is in release position, care should be exercised that the brake-pipe does not become overcharged. This action does not release the locomotive brakes. If the handle is moved from release to holding position, the locomotive brakes will still remain applied. They may be graduated off by short successive movements of the handle between running and holding positions, or by placing the handle at once in the running position. If a full stop is not desired, the handle of the automatic brake-valve should be placed in service position until the required reduction in brake-pipe pressure is obtained; then moved to lap position. After the speed has dropped sufficiently, place the handle in release position until all the train brakes are released and the slack has had an opportunity to adjust itself; then place the handle in running position to release the locomotive brakes.

An emergency application is made with the automatic brake-valve in exactly the same manner as with the engineer's brake-valve commonly installed on locomotives.

If only the independent brake-valve is being used, the handle of the automatic brake-valve should be carried in running position. The locomotive brakes may be released by placing the handle of the independent brake-valve in running position. When the handle of the automatic brake-valve is not in running position, the only way in which the locomotive brakes can be released is by placing the handle of the independent brake-valve in release position. The locomotive brakes may be released under any and all conditions by placing the handle of the independent brake-valve in release position. The independent brake-valve should be used very carefully when handling long trains or in switching service, as damage to draft gears might result if the slack in the train is permitted to run out hard. If an emergency case arises, the automatic brake should be applied instantly, even though the independent brake is being used. The safety-valve on the distributing valve will prevent any excessive brake-cylinder pressure on the locomotive.

In handling trains on long grades, the application of the train brakes and locomotive brakes should be alternated to prevent any overheating of the wheels. When leaving the locomotive while doing work about or near it, the independent brake-valve should always be left in application position.

When double-heading, the double cut-out cock in the brake-pipe below the automatic brake-valve should be closed, and the valve should be left in lap position, except on the locomotive from which the brakes are being operated.

In order to simplify the description of the various parts of the equipment, the following names of pipes are given (see Fig. 24):

Reservoir Pipe. The pipe connecting the main reservoir to the automatic brake-valve, distributing valve, feed-valve, and reducing valve.

Feed-Valve Pipe. The pipe connecting the feed-valve to the automatic brake-valve.

Reducing-Valve Pipe. The pipe connecting the reducing valve to the independent brake-valve and the air-signal system.

Brake-Pipe. The pipe connecting the automatic brake-valve to the distributing valve and the triple valves on the cars in the train.

Brake-Cylinder Pipe. The pipe connecting the distributing valve to the brake-cylinders on the engine and tender.

Application-Chamber Pipe. The pipe connecting the application chamber of the distributing valve to the automatic brake-valve, through the independent brake-valve.

Double-Heading Pipe. The pipe connecting the application chamber of the distributing valve to the automatic brake-valve, through the double cut-out cock.

The main-reservoir cut-out cock is used to cut off the supply of air when removing any part of the equipment for cleaning or repairing, except the governor. Before it is closed, however, the double cut-out cock below the automatic brake-valve should be turned to close the brake-pipe, and the handle of the automatic brake-valve should be placed in release position. This is done so as to prevent lifting from its seat the rotary valve of the automatic brake-valve or the slide-valve of the feed-valve. The automatic brake-valve receives air from the main reservoir direct and through the feed-valve. The check-valve in the signal pipe prevents air from flowing back from the signal pipe when the independent brake-valve is being used. The pump-governor has three pipe connections—one from the reservoir pipe to the maximum pressure head; one from the feed-valve pipe to the upper connection of the excess pressure head; and one from the automatic brake-valve to the lower connection of the excess pressure head.

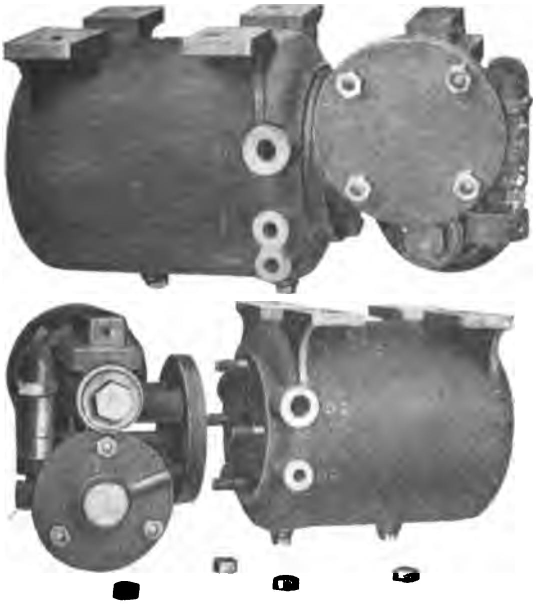
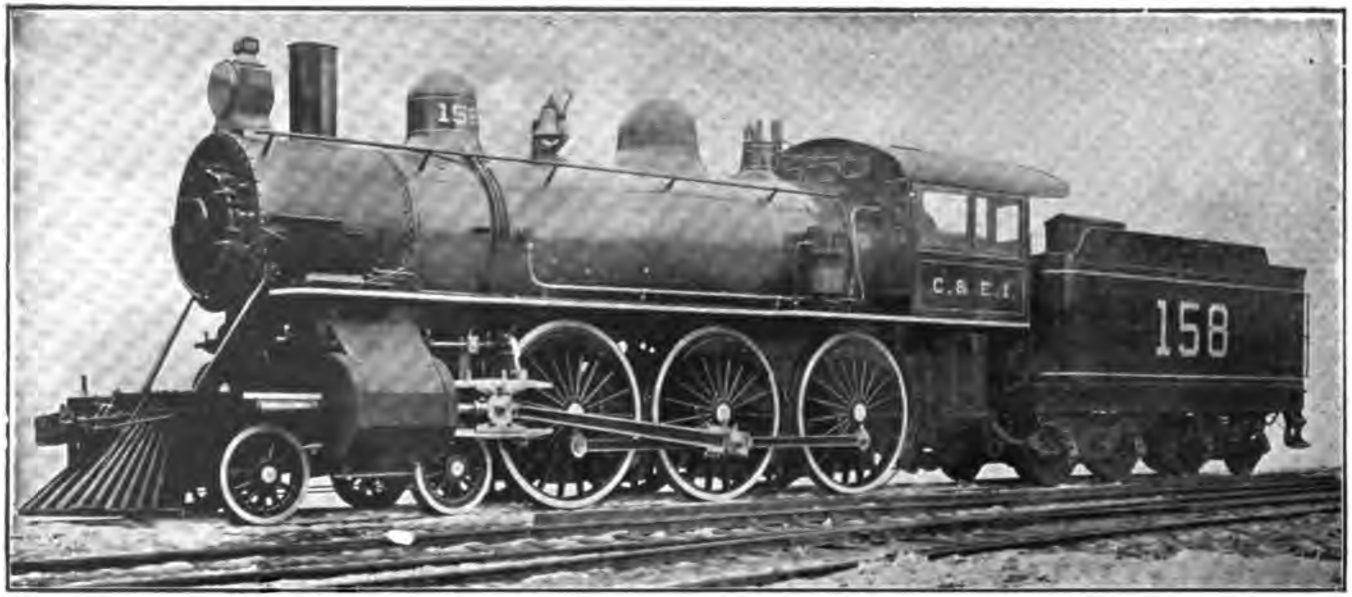


Fig. 25. Distributing Valve and Double-Chamber Reservoir of "ET" Equipment.

Distributing Valve. The distributing valve, shown in Figs. 25 and 26, has five pipe connections. On the reservoir are cast the following letters indicating these connections: *MR*—main reservoir



Representative American Locomotive, Built by the American Locomotive Company.

pipe; *DH*—double-heading pipe; *AC*—application-chamber pipe; *BC*—brake-cylinder pipe; and *BP*—brake-pipe.

Fig. 27 is a section through the distributing valve. The principles governing the operation of this valve are the same as those previously described in the standard equipment commonly used. The chief difference is the manner in which air-pressure is supplied to the brake-cylinders of the locomotive. It consists chiefly of a plain triple valve, an auxiliary reservoir, and a small brake-cylinder, the

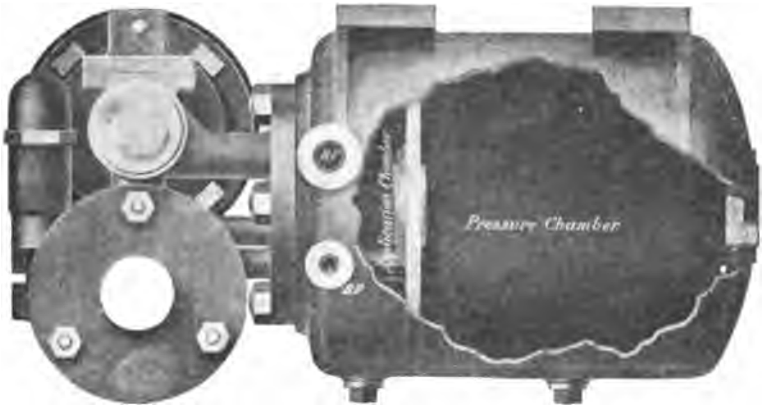


Fig. 26. Part Sectional View of Distributing Valve and Double-Chamber Reservoir of "ET" Equipment.

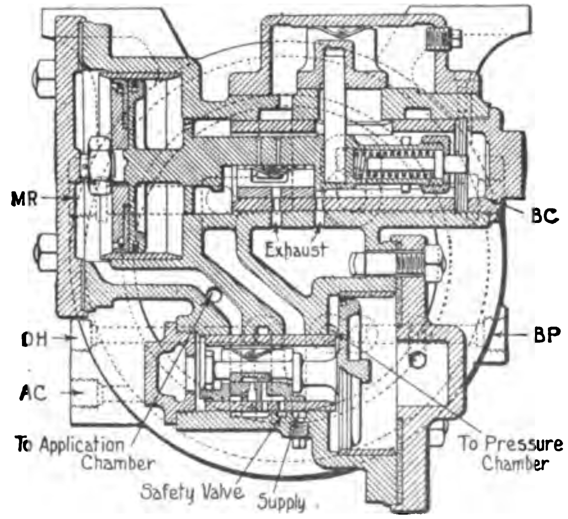
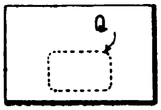
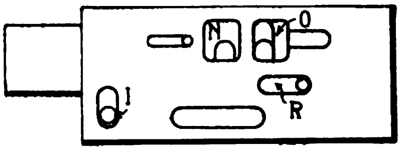


Fig. 27. Section through Distributing Valve of "ET" Equipment.

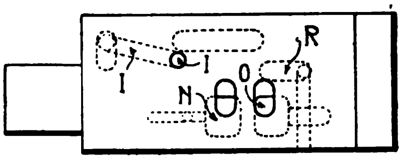
piston-rod of which operates two slide-valves instead of being connected to the brake-rigging. The piston travel is always constant. One of the slide-valves mentioned admits air to the brake-cylinders of the locomotive, and the other releases or exhausts this air. The triple valve and auxiliary reservoir are used in automatic applications only, and are called, respectively, the *equalizing portion* and the



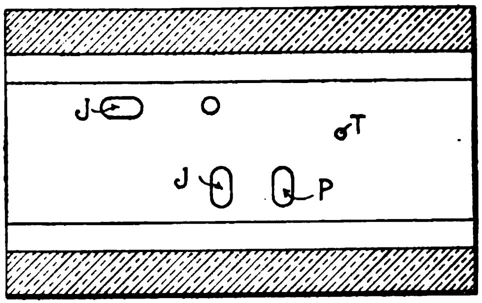
Plan of Graduating Valve.



Face of Slide Valve.



Plan of Slide Valve.



Plan of Slide Valve Seat.

Fig. 28. Graduating Valve, Equalizing Slide-Valve, and Slide-Valve Seat of Distributing Valve of "ET" Equipment.

pressure chamber. The slide-valve connected to the piston-rod of the small brake-cylinder, which admits air to the brake-cylinders of the locomotive, is called the *application valve,* while that one which exhausts this air is called the *exhaust valve.* It is easily seen that the entire operation of the locomotive brakes consists in admitting or releasing air-pressure into or out of the application chamber. In independent applications, this is done directly by operating the independent brake-valve; while in automatic applications, it is accomplished by means of the equalizing piston and the air-pressure stored in the pressure chamber.

Fig. 28 is given to show the correct location of ports in the equalizing valve and slide-valve.

Since the ports in the valve cannot be clearly indicated in Fig. 27, diagrammatic illustrations shown in Figs. 29, 30, 31, 32, 33, 34, 35, and 36 will be referred to in explaining the operation of the valve. These diagrams show the parts distorted and not as actually constructed.

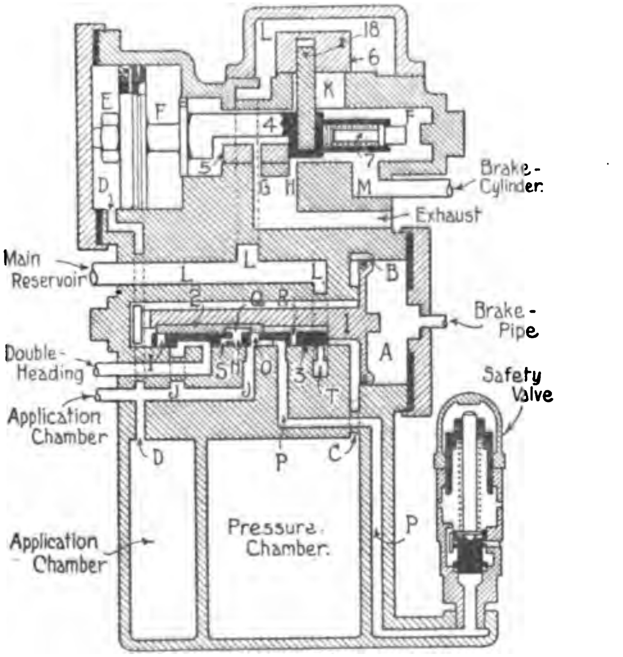


Fig. 29. Distributing Valve, Charging or Release Position, Automatic or Independent.

The operation of the valve when automatic applications are made, is as follows:

Charging. Fig. 29 shows the movable parts of the valve in charging position. In this position, the chamber *A* is in connection with the brake-pipe; and air is free to pass around the top of the piston

(1) through the feed-groove *B* and the port *C*, to the pressure chamber, until the pressure on both sides of the piston becomes equal.

Release. The position shown in Fig. 29 is also the release position, and is the position the parts take when the automatic brake-valve handle is placed in release position. In this position, the pressure in the chamber *A* is greater than that in the application chamber; consequently the equalizing piston (1) is moved to the position shown. This movement of the piston moves the graduating valve (2) and the slide-valve (3) to the release position shown, but does not release the locomotive brakes. To accomplish this, either the automatic brake-valve must be placed in running position or the independent brake-valve must be moved to release position. In either case, the application-chamber pipe is opened to the atmosphere, and the air in the application chamber is exhausted. The air in the chamber *E* will also be exhausted, since it is connected to the application chamber by the port *D*. This permits the brake-cylinder pressure in the chamber *F* to move the piston (4) to the left until the exhaust ports *G* and *H*

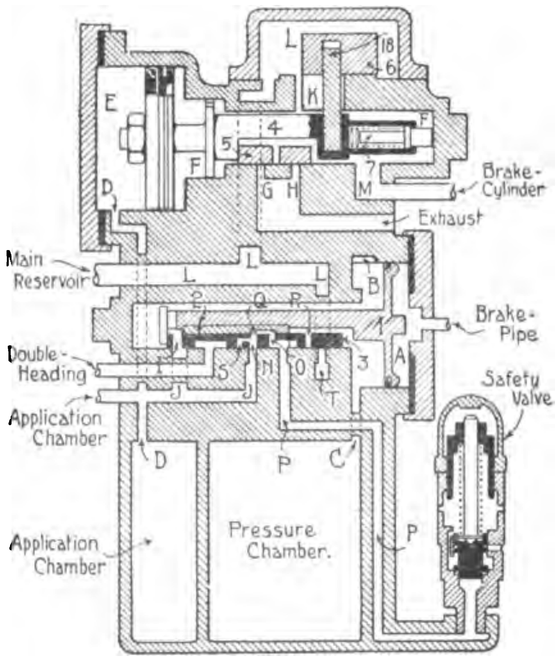


Fig. 30. Distributing Valve, Automatic Service Position.

permit the brake-cylinder pressure to escape. The double-heading pipe must always be kept closed at the double cut-out cock below the automatic brake-valve, unless there are two engines at the head of the train. In this case, the engine from which the brakes are controlled should have its double-heading pipe closed, while on the other engine it should be open.

Service. When a service application is made with the automatic brake-valve, the brake-pipe pressure in the chamber *A* is reduced; and piston (1), together with the graduating valve (2) and the slide-valve (3), is moved toward the right to the position shown in Fig. 30. In this position, the port *I* in the slide-valve registers with the port *J* in the seat, and permits air from the pressure chamber to flow into the application chamber and the chamber *E* through the port *D*. This pressure forces the application piston (4) to the right, causing the exhaust valve (5) to close the exhaust ports *G* and *H*, and the application valve (6) to uncover the port *K*; also causing the graduating spring on the stem (7) to be compressed. Air from the main reservoir

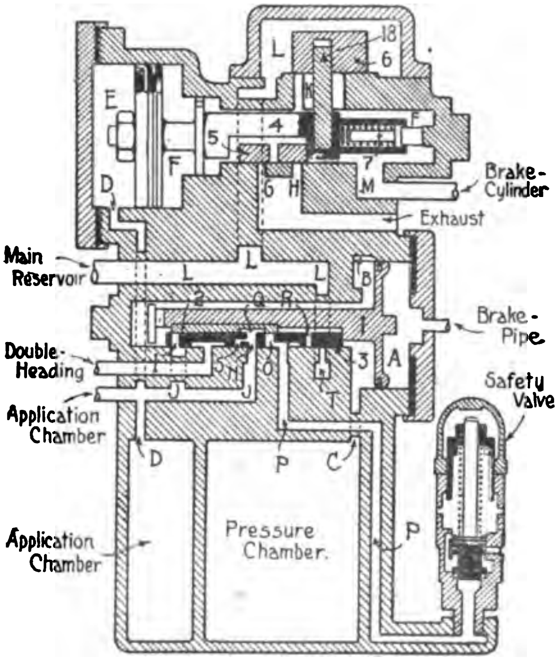


Fig. 31. Distributing Valve.- Service Lap Position.

is now free to flow from the chamber *L* through the port *K* and passage *M* to the brake-cylinders.

In the movement just described, the ports *N* and *O* in the slide-valve register with the ports *J* and *P* in the seat, and are connected by the cavity *Q* in the graduating valve. This connects the application chamber with the safety-valve, which, being adjusted to open at 53 pounds, limits the cylinder pressure to this amount during a full service application.

Service Lap. If the brake-pipe reduction is not sufficient to cause a full service application, the air from the pressure chamber continues to discharge until the difference in pressure on the two sides of the piston (1) forces it and the graduating valve (2) toward the left. The frictional resistance of the slide-valve (3) prevents any further movement after the shoulder on the piston (1) strikes the right end of the slide-valve. In this position, all ports are closed, as in Fig. 31, and the valve is in *service lap.* Air continues to flow through the port *K* and the passage *M* into the brake-cylinders, until their pressure is

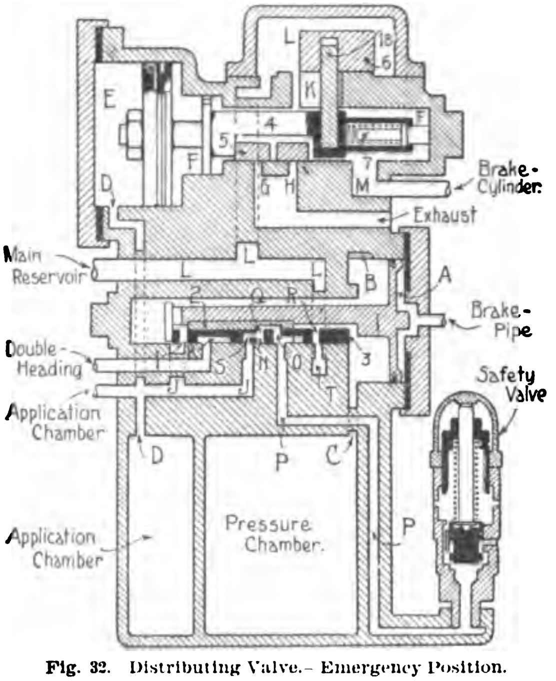


Fig. 32. Distributing Valve.—Emergency Position.

slightly in excess of that in the application chamber. This difference in pressure on the two sides of the piston (4), assisted by the graduating spring on the stem (7), forces the piston (4) to the position shown in Fig. 31. This movement of the piston (4) results in application valve (6) closing the port *K*, but does not move the exhaust valve (5). The brake-cylinder pressure is then about the same as that in the application chamber.

Emergency. When a sudden and heavy reduction of air-pressure is made in the brake-pipe, the piston (1) is forced to the right by the pressure in the pressure chamber until it strikes the gasket as shown in Fig. 32. This movement causes the slide-valve (3) to uncover the port *J;* and air from the pressure chamber passes quickly into the application chamber and becomes equalized. When the automatic brake-valve is placed in emergency position, the ports in the valve connect the equalizing reservoir to the application-chamber pipe. Air from the equalizing reservoir then passes into the application chamber, and, with that from the pressure chamber, equalizes at about 60 pounds. Air from the main reservoir enters the slide-valve chamber through the pipe *L* and the ports *T* and *R*, and passes into the pressure and application chambers. Air now escapes from the application chamber through the port *J* into the cavity *S*, through a small port into the port *N*, and thence out through the safety-valve. Air escapes through the safety-valve more rapidly than it can be supplied through the ports *R* and *T*, and thus prevents the pressure from becoming higher than is desired.

In high-speed service, the feed-valve is set to maintain a brake-pipe pressure of 110 pounds instead of 70; and a main-reservoir pressure of 130 or 140 pounds is carried. The pressure in the application chamber, under these conditions, is increased to about 85 pounds; but air escapes through the cavity *S* and port *N* at about the same rate as in the high-speed reducing valve, until the pressure is only about 60 pounds. The pressure in the application chamber does not drop below about 60 pounds, because, under these conditions, air from the main reservoir is supplied through the ports *R* and *T* faster than it can escape through the restricted passages to the safety-valve.

Emergency Lap. In emergency applications, the process above described continues until the brake-cylinder pressure slightly exceeds the pressure in the application chamber, when all parts move back to emergency lap position, as shown in Fig. 33. Release is accomplished in the same manner as described under Fig. 29.

In operating the locomotive brakes with the independent brake-valve, the action of the distributing valve is as follows:

Independent Application. When making an application, the equalizing piston (1) occupies the same position as shown in Fig. 34. Air is admitted into the application chamber from the main reservoir through the reducing valve, at 45 pounds' pressure. This pressure also exists in the chamber E, and forces the piston (4) to the right, as shown. This movement causes the application valve (6) to uncover the port K, and air from the main reservoir passes through the passage M into the brake-cylinders. Air continues to flow into the brake-cylinders until their pressure and that in the chamber F slightly exceeds that in the chamber E, when the piston (4) will be moved to the left, causing the application valve (6) to close the port. This position, shown in Fig. 35, is known as *independent lap.*

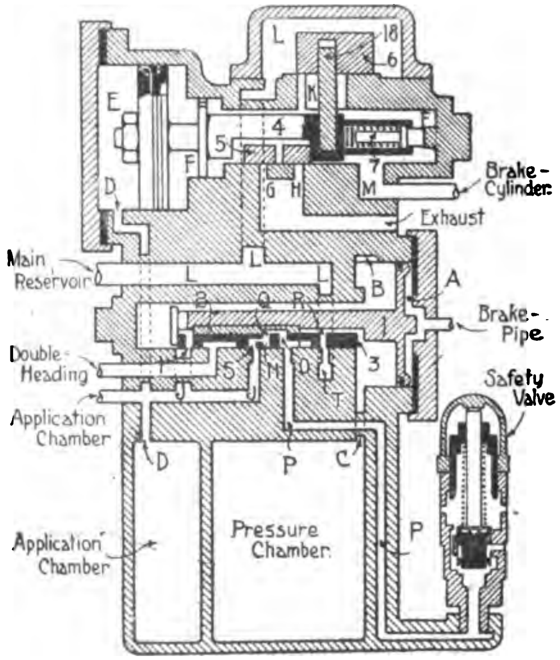


Fig. 33. Distributing Valve.—Emergency Lap Position.

It is easily seen that the action of the piston (4) will always maintain about the same pressure in the brake-cylinders as exists in the application chamber.

Independent Release. If the handle of the independent brake-valve is placed in release position, the air in the application chamber escapes directly to the atmosphere. This permits the brake-cylinder pressure in the chamber F to force the piston (4) to the left, causing the application valve (6) to close the port K, and the exhaust valve (5) to open the ports G and H, as shown in Fig. 29. Air is now free to escape from the brake-cylinders until the valve is placed in lap position or until the brake-cylinders are entirely exhausted. If the handle of the independent brake-valve is placed in lap position before all the air is exhausted from the brake-cylinders, the parts of the distributing valve will move to independent lap position, as shown in Fig. 35. In this way, the independent release may be graduated as desired.

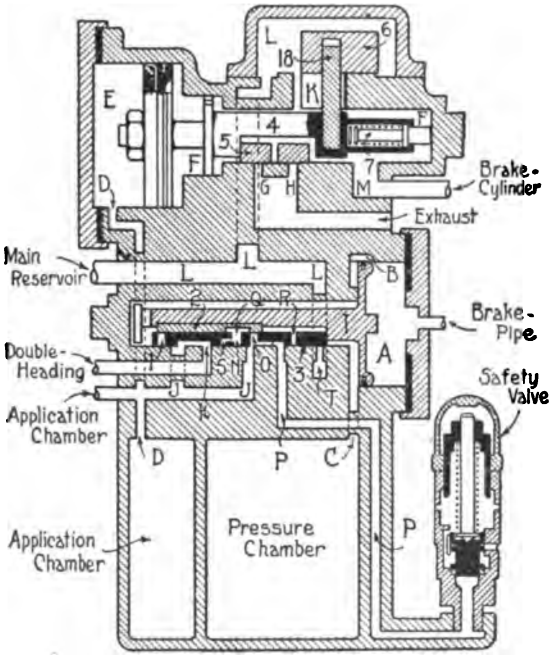


Fig. 34. Independent Application of Distributing Valve.

Safety-Valve. One of the essential parts of the distributing valve is the safety-valve. The principle of its action is shown in the section given in Fig. 36. Its construction is such as to cause it to close quickly with a *pop* action, which insures a firm seating. The spring should be adjusted so that the valve will open at 53 pounds. This is accomplished by removing the cap nut (1) and screwing, up or down, an adjusting nut (2).

Automatic Brake-Valve. The automatic brake-valve not only performs the functions of the standard engineer's valve commonly installed on locomotives, but also those necessary to obtain all the desirable features of the distributing valve.

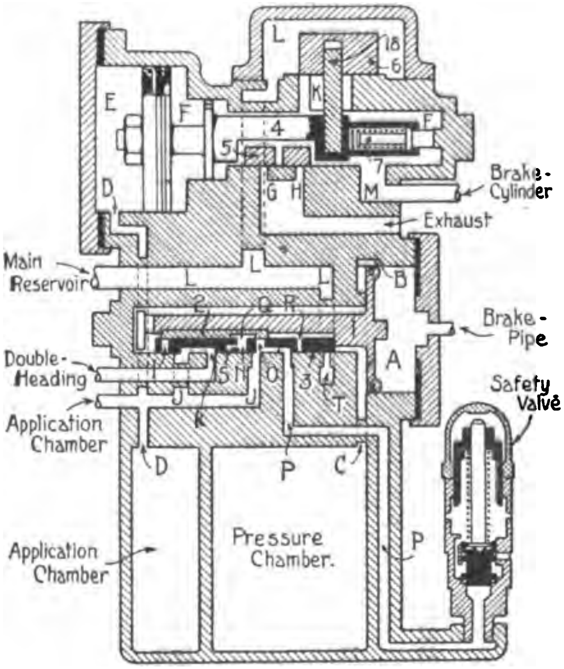


Fig. 35. Distributing Valve.—Independent Lap Position.

Fig. 37 is taken from a photograph of this valve, with the handle in running position.

Fig. 38 is a top view, showing the six positions of the brake-valve handle.

Fig. 39 shows two views, the upper one being a section through the rotary-valve chamber, the rotary valve being removed; and the lower one, a vertical section of the entire valve. A plan of the top view of the rotary valve is shown on the left.

The description of the operation of the valve in its different positions, will be given in the order in which it is most generally used.

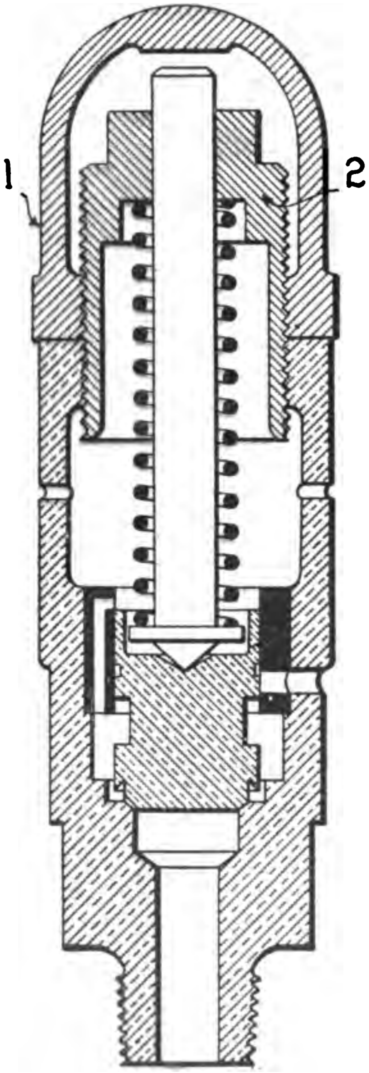


Fig. 36. Section of Safety-Valve of Distributing Valve.

Charging or Release Position. In this position, air flows directly from the main-reservoir pipe, through the port *A* in the rotary valve and the port *B* in the valve-seat, into the brake-pipe. This quickly recharges the train-brake system and releases the train brakes, but does not release the locomotive brakes, if they are applied. The port *C* now registers with the port *D*, and permits main-reservoir pressure to enter the chamber *E*, and acts on the equalizing piston (2), forcing it downward and closing the discharge valve. In this position, the port *F* in the rotary valve (1) registers with the warning port *G* in the valve-seat, permitting a small amount of air to escape into the exhaust cavity *H*. This serves to make enough noise to attract the engineer and notify him that the valve still remains in release position. A small groove in the face of the rotary valve connects the port *F* with the port *I*, and permits main-reservoir pressure to act on the excess-pressure head of the pump-governor. If the handle of the automatic brake-valve is permitted to remain in this position too long, the brake-pipe and auxiliary reservoirs would become charged to main-reservoir pressure. The handle should be moved to *running* or *holding* position before this occurs.

Running Position. In running position, all the train and locomotive brakes are released, and the auxiliary reservoirs are charged. The ports *J* and *B* in the valve-seat are connected by the cavity *K* in the rotary valve; and air from the feed-valve pipe passes directly into the brake-pipe and recharges the auxiliary reservoirs. The air in the brake-pipe will not attain a pressure greater than that for which the feed-valve is set. The ports *L* and *M* in the valve-seat are connected by the cavity *N* in the rotary valve; and the pressure on the equalizing piston (2) and in the equalizing reservoir is the same as that in the brake-pipe. The port *F* in the rotary valve registers with the port *I* in the valve-seat, and permits main-reservoir pressure to pass to the excess-pressure head of the pump-governor. The port *O* in the rotary valve registers with the port *P* in the valve-

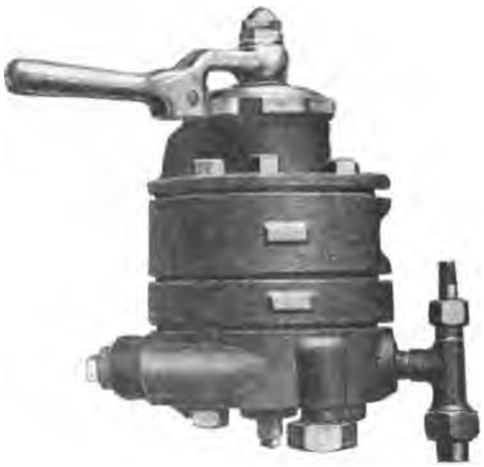


Fig. 37. Automatic Brake-Valve.

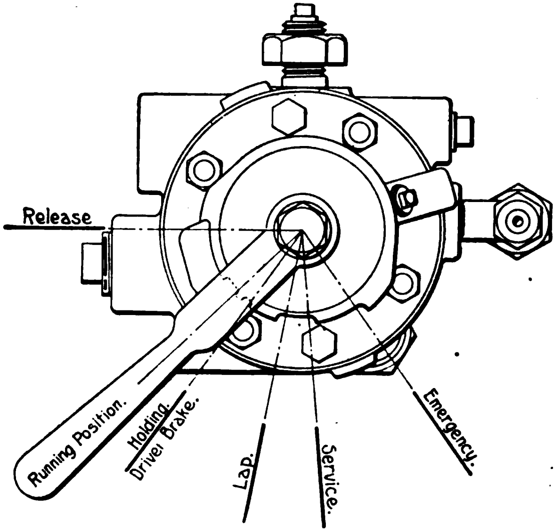


Fig. 38. Top View of Automatic Brake-Valve, Showing Six Positions of Handle.

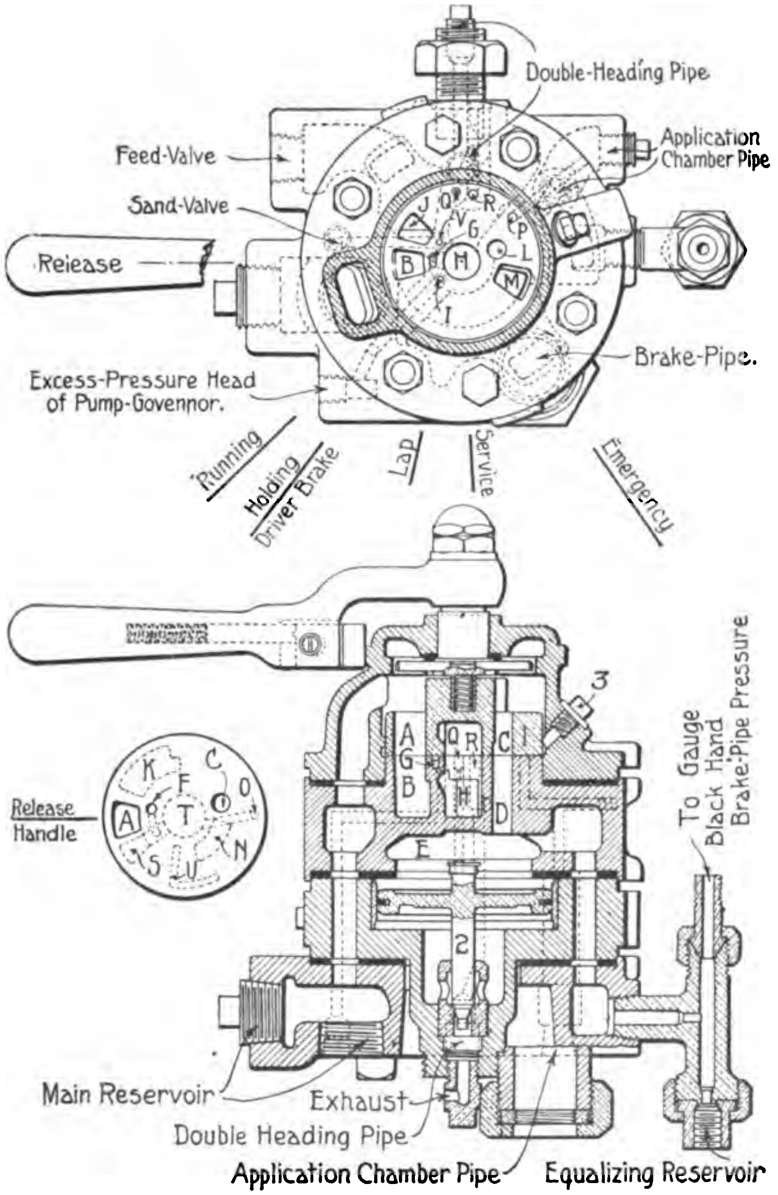


Fig. 39. Sectional Views of Automatic Brake-Valve.
Upper view, a horizontal section through rotary-valve chamber, rotary valve removed. Plan view of rotary valve shown at left. Lower view, a vertical section through entire valve.

seat, and connects the application-chamber pipe with the exhaust cavity *H*.

Service Position. In this position, the brake-pipe pressure is gradually reduced and causes a service application. The port *O* in the rotary valve registers with *Q* in the valve-seat, and permits air to discharge from the chamber *E* and the equalizing reservoir into the exhaust chamber *H*. The port *Q* is restricted, and causes a gradual discharge of air from the equalizing reservoir. As the pressure above the equalizing piston (2) is reduced, the brake-pipe pressure below forces the piston (2) upward, opening the discharge valve and exhausting air from the brake-pipe into the atmosphere. When the pressure in the chamber *E* is reduced the required amount, the handle of the brake-valve is moved to lap position. Air will continue to exhaust from the brake-pipe through the discharge valve, until the pressure below the piston (2) is slightly less than that above. Equalizing piston (2) will then be forced downward, closing the equalizing valve. By this process, it will be seen that the reduction of the pressure in the equalizing reservoir determines that in the brake-pipe.

Lap Position. This is the position the valve occupies while holding the brakes applied, to prevent loss of air from the main reservoir in case of a break-in-two, and when another engine in the train is handling the brakes. All ports are closed except the port *O* in the rotary valve, which connects with the port *R* in the valve-seat. In double-heading, these ports connect with the application chamber in the distributing valve, and permit the air to exhaust into the atmosphere when the automatic brakes are being released.

Release Position. The action of the valve in this position has been described under *charging* or *release.*

Holding Position. In this position, all train brakes are released, but the locomotive brakes are held applied. The only difference between the *running* and *holding* positions is that in the former the application chamber of the distributing valve is open to the atmosphere, while in the latter it is not.

Emergency Position. In this position, the port *S* in the rotary valve registers with the port *M* in the seat, and air discharges from the brake-pipe through the cavity *T*, into the exhaust chamber *H*. These ports are proportioned in such a manner that a large volume of air is suddenly discharged from the brake-pipe, causing all triple valves and the distributing valve to go to the emergency position. The cavity U in the rotary valve registers with L and P in the valve-seat, and permits the air from the equalizing reservoir to flow into the application chamber of the distributing valve. The ports C and V register, and allow air from the main reservoir to flow to the sand valve, thus applying sand to the rails.

Plug 3, shown in Fig. 39, is placed in the top of the case at a point to fix the level of an oil bath in which the rotary valve operates.

Independent Brake-Valve. The independent brake-valve is of the rotary-valve type. Fig. 40 is taken from a photograph of the valve. The general construction of the valve is represented in Fig. 41. The lower view shows a vertical section of the entire valve, with a top view of the rotary valve on the right; while the upper one shows a horizontal section taken through the valve body with the rotary valve removed. All pipe connections, and the different positions of the handle, are shown.

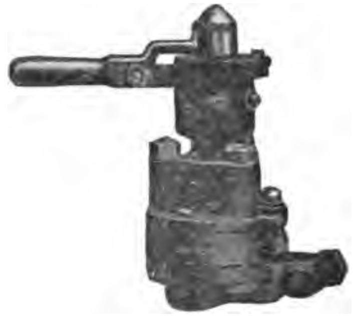


Fig. 40. Independent Brake-Valve.

The action of the valve when placed in the different positions is as follows:

Running Position. When the independent brake is not in use, the independent brake-valve should always be carried in this position. The ports A and B in the valve-seat are connected by the port C in the rotary valve (1). This establishes communication between the application chamber of the distributing valve and the port P (see Fig. 39) of the automatic brake-valve, so that the former can be operated by the latter. If the independent brakes are being operated with the automatic brake-valve in running position, they can be released by simply moving the independent brake-valve to running position, since in this position the air in the application chamber of the distributing valve can escape through the automatic brake-valve.

Service Position. In this position, the ports D and B in the valve-seat are connected by the groove E in the rotary valve, allowing air to flow from the main reservoir to the application chamber. The air-supply from the main reservoir is reduced by the reducing valve to 45 pounds. This is the maximum pressure that can be obtained in the brake-cylinders when using the independent brake-valve.

Lap Position. This position is used to hold the locomotive brakes after having been applied by using the independent brake-valve. All operating ports are closed.

Release Position. In this position, the locomotive brakes will be released when the automatic brake-valve is not in running position.

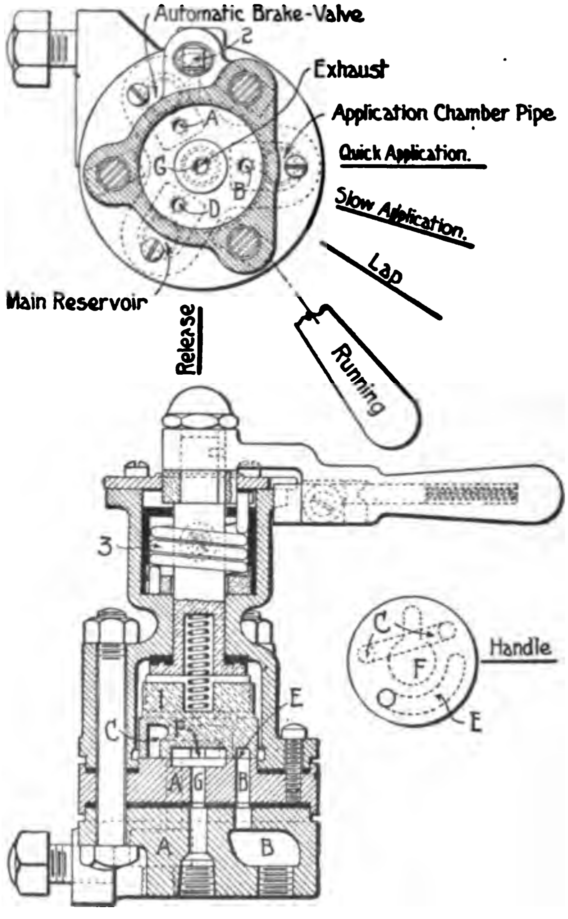
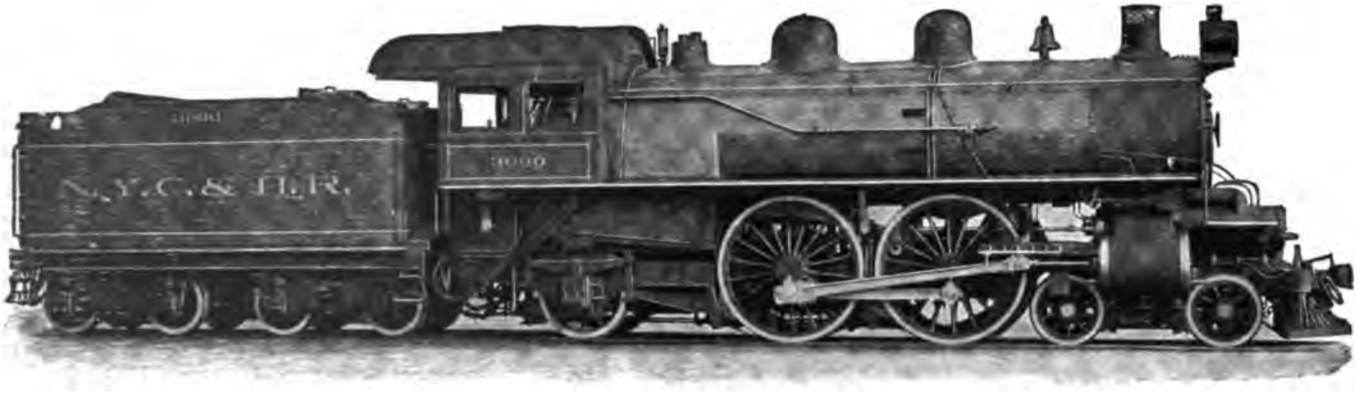


Fig. 41. Sectional Views of Independent Brake-Valve.
Upper view, a horizontal section through valve body, rotary valve removed. Lower view, a vertical section through entire valve. Plan view of rotary valve shown at right.

The port *B* in the valve-seat registers with the cavity *F* in the rotary valve, and air from the application chamber of the distributing valve exhausts into the atmosphere.



PASSENGER LOCOMOTIVE FOUR-CYLINDER BALANCED COMPOUND.
Built for New York Central and Hudson River Railroad.

If the valve is left in this position, it is impossible to operate the locomotive brakes by means of the automatic brake-valve. For this reason, the coil spring (3) is provided, which always returns the handle to release position as soon as the engineer lets go of it. The purpose of the oil plug (2) is the same as that described in connection with the automatic brake-valve.

Reducing Valve. This is shown in Fig. 42, and is almost identical with the feed-valve. The only difference in their construction is in the manner of adjustment. The principle of its action has already been described.

Pump-Governor. The pump-governor is shown in Fig. 43, with its different pipe connections named. When the automatic brake-valve is in release, running, or holding position, air from the main reservoir flows through the automatic brake-valve into the chamber *A* below the diaphragm (1). Air from the feed-valve enters above the diaphragm (1), assisting the spring (2) to hold it down. Since the spring (2) is adjusted to a compression of 20 pounds, the diaphragm (1) will not be lifted until the main-reservoir pressure exceeds the feed-valve pipe pressure by this amount. When this occurs, the diaphragm (1) is lifted, and the pin valve is opened. This permits main-reservoir pressure to act on the piston (3), forcing it downward and practically stopping the pump. When the main-reservoir pressure in the chamber *A* becomes slightly reduced, the diaphragm (1) is forced downward and the pin valve is closed. The air confined above the piston (3) escapes through the port *B*; the piston (3) is lifted by the action of the spring (4); and the pump starts working. When the automatic brake-valve is in any position other than release, running, or holding, the port connecting the automatic brake-valve with the chamber *A* is closed, and this governor head is cut out of action. The pump is then controlled by the other governor head, which is always connected with the main reservoir. Its action is similar to that just described. Both governor heads are adjusted by

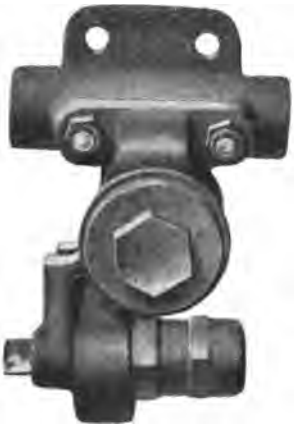


Fig. 42. Reducing Valve.

screwing up or down on adjusting plugs (5). As both governor heads have a small vent port *B* from which air escapes whenever pressure is present above the piston (3), one of these should be plugged to avoid a waste of air. A small port in the valve (6) permits steam to enter the pump when it is cut out of action by the governor, which prevents freezing in cold climates.

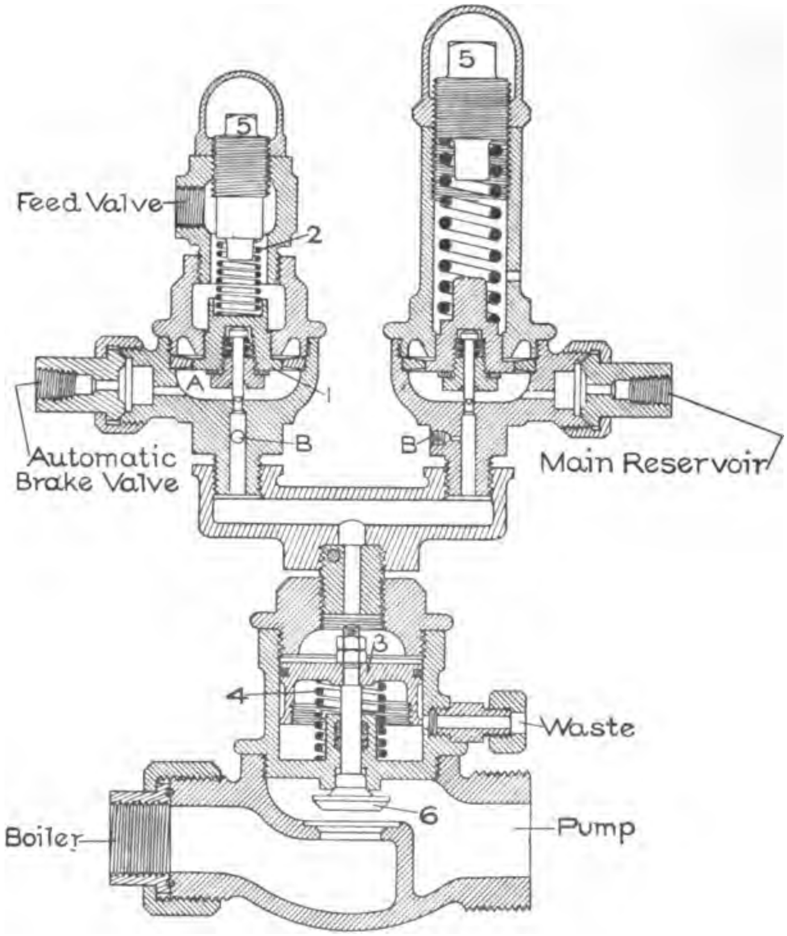


Fig. 43. Vertical Section through Pump-Governor.

WESTINGHOUSE TYPE "K" TRIPLE VALVE

The standard form of quick-action triple valve commonly used in freight and passenger service, has until recently proven very satisfactory. In the last few years, however, with heavier locomotives capable of handling 100-car trains fitted with air-brake equipment, they have failed to meet all the requirements. Realizing the changed conditions and the importance of meeting them, the Westinghouse Company has recently perfected the "K" triple valve.

Some of the undesirable features of the standard quick-action triple which the "K" triple overcomes, are as follows:

(*a*) The failure of a portion of the brakes in a long train to apply.

(*b*) A complete release of the brakes at the forward end of the train before the brake-pipe pressure which has brought this about can reach the triple valves near the end of the train. This action permits the slack to run out hard, and creates excessive strains on the draft gears, often resulting in a break-in-two.

(*c*) Overcharging the auxiliary reservoirs at the forward end of the train while releasing the brakes. The result of this action is a re-application of the forward brakes when the brake-valve handle is placed in running position.

The outward appearance of the "K" triple valve, when attached to the auxiliary reservoir, is so much like the standard quick-action triple that a thin web is cast on the top part of the body as a distinguishing mark. The designating mark "K-1" or "K-2" is also cast on the side of the body. The "K" triple is made in two sizes—the "K-1" for use with the 8-inch freight-car brake-cylinder; and the "K-2," with the 10-inch freight-car brake-cylinder (see Fig. 44).

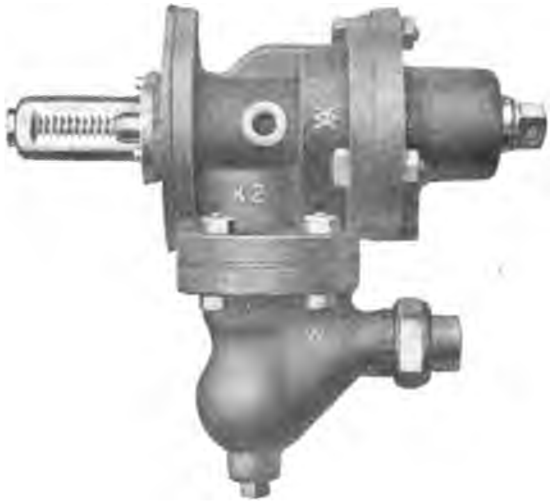


Fig. 44. Westinghouse Type "K" Freight Triple Valve.

This new valve embodies every feature possessed by the standard quick-action triple, and three additional ones—namely, the *quick service*, *retarded release*, and *uniform recharge*. It operates in perfect harmony with the standard triple, and often improves the action of the latter when the valves are mixed in the same train. The two types of valves have many parts in common and are interchangeable. The standard triple may be transformed into the "K" triple by preserving all of the old parts, save the body, slide-valve, bush, and graduating valve. This transformation can be done at a minimum cost when the valves are returned to the works for heavy repairs.

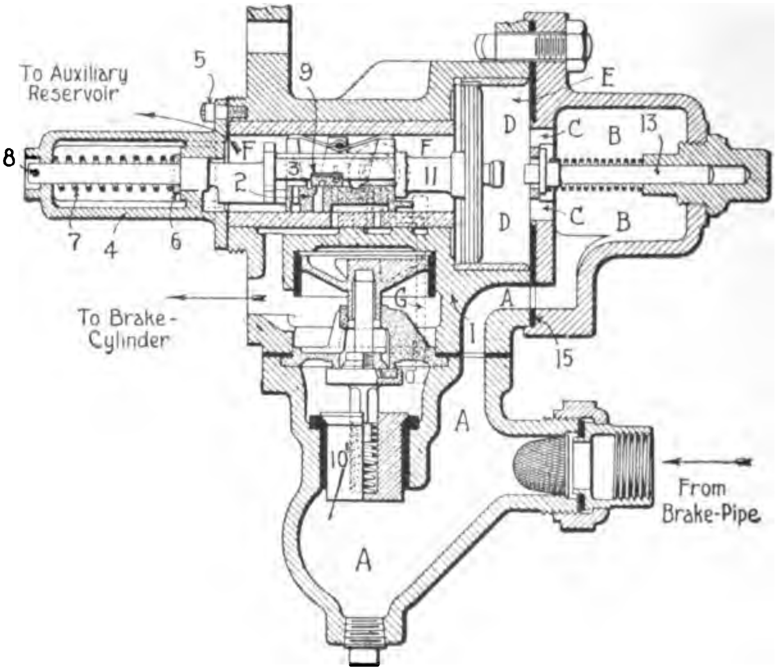


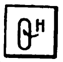
Fig. 45. Vertical Section through "K-2" Triple Valve, Showing General Arrangement of Valves and Ports.

A side view of the "K" triple valve, and the general arrangement of valves and ports, are shown in Figs. 45 and 46. Referring to Fig. 45, those parts which are different and not found in the standard triple, are as follows: *Valve Body* (1), *Slide-Valve* (2), *Graduating Valve* (3), *Retarding-Device Bracket* (4), *Retarding-Device Screw* (5), *Retarding-Device Washer* (6), *Retarding-Device Spring* (7), *Retarding-Device Stem Pin* (8), and *Graduating-Valve Spring* (9).

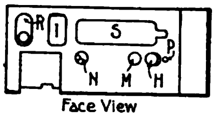
The *quick-service* feature gives a rapid serial operation of all brakes in service application. This is accomplished by using the principle of the standard triple in emergency applications—namely, discharging brake-pipe air into the brake-cylinder. That is, in service applications, some air from the brake-pipe passes into the brake-cylinder. The result is that the quick-service feature insures the operation of every brake, reduces the amount of air exhausted at the engineer's brake-valve and the possible loss of air due to flowing back through the feed-groove, and effects a saving of air.

The *retarded-release* feature operates so as to give practically a simultaneous release of all brakes in the train. This is accomplished by automatically restricting the exhaust of air from the brake-cylinder in the forward portion of the train, and allowing the others to release freely. This retarded release is due to the increased pressure which exists in the forward end of the brake-pipe when the brake-valve is in release position, and affects about the first thirty cars in the train.

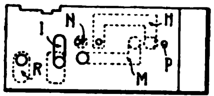
The *uniform recharge* of the auxiliary reservoirs in the train is due to the fact that when the valve is in the retarded-release position, the ports connecting the brake-pipe with the auxiliary reservoir are automatically restricted. In other words, as long as the exhaust from the brake-cylinder is retarded, the recharge is restricted. This feature not only prevents the overcharging of the auxiliary reservoirs on the front cars, but, by drawing less air from the brake-pipe, permits the increase in brake-pipe pressure to travel more rapidly to the rear cars, where it is most needed for releasing and recharging those brakes.



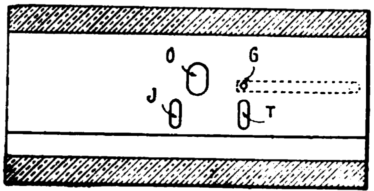
Face View Graduating Valve.



Face View



Top View Slide Valve.



Slide Valve Bush.

Fig. 46. Views of Graduating Valve, Slide-Valve, and Slide-Valve Bush of "K-2" Triple Valve.

By reference to Fig. 46, which shows views of the graduating valve, slide-valve, and slide-valve bush, it will be seen that the ports are arranged along a longitudinal center line, making it very difficult to follow the course of air through them with a sectional view such as is shown in Fig. 45. For this reason, diagrammatic views shown in Figs. 47, 48, 49, 50, 51, and 52 are used in explaining the operation of the valve. In order to assist to a clearer understanding of the valve, the notation used to distinguish ports, valves, etc., is the same in all figures.

Referring to Fig. 45, the retarding-device brake (4) projects into the auxiliary reservoir; and its construction is such that free communication exists between the auxiliary reservoir and the chamber containing the slide-valve and the graduating valve. The graduating valve is of the slide-valve type, and moves over the top of the slide-valve, being carried along by the triple-valve piston. The friction between the slide-valve and its seat prevents its movement until it is actuated by the triple-valve piston.

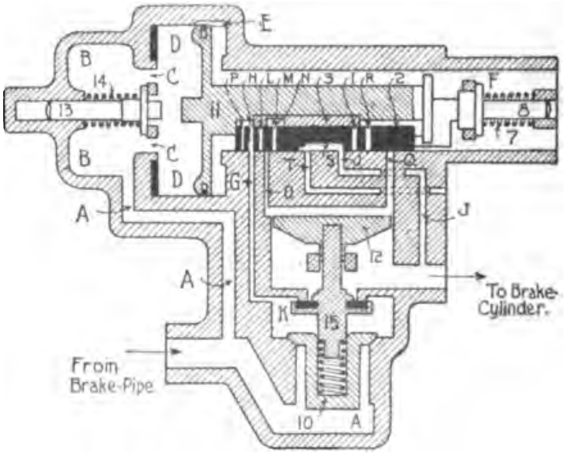


Fig. 47. "K" Triple Valve in Full-Release and Charging Position.

The operation of the "K" triple valve is as follows:

Full-Release and Charging Position. Fig. 47 shows the valve in this position. Air enters from the brake-pipe, and passes through the port *A* into the chamber *B*, through the ports *C*, into the cylinder *D*, through the feed-groove *E*, into the chamber *F* above the slide-valve, and finally passes into the auxiliary reservoir. The feed-groove *E* is the same size as that used in the standard triple. In the "K-2" triple, the port *H* is added to the slide-valve, through which air entering from the port *G* can feed into the auxiliary reservoir in order that a greater volume of air can be handled to supply the auxiliary reservoir of a 10-inch brake-cylinder. The port *H* is not placed in the "K-1" triple. Brake-pipe pressure, entering by the port *A*, lifts the check-valve (10), passes through the ports *G* and *H* into the chamber *F*, and thence into the auxiliary reservoir.

The process described above continues until the pressure in the auxiliary reservoir and brake-pipe become equal. The auxiliary reservoir is then said to be fully charged.

Quick-Service Position. In making a service application of the brakes, air is slowly exhausted from the brake-pipe, and the pressure in the chamber *D* is reduced. When the difference in the auxiliary reservoir and brake-pipe pressures is sufficient to overcome the friction of the piston (11) and the graduating valve (3), the piston moves to the left. As the piston (11) moves to the left, a shoulder on the right end of the piston strikes the right end of the slide-valve (2) and moves it to the left until the piston (11) strikes the end of the graduating stem (13). The parts of the valve then occupy the position shown in Fig. 48. In this position, air flows from the auxiliary reservoir into the chamber *F* through the ports *I* and *J*, into the brake-cylinder. At the same time, the small amount of air contained in the cavity *K* passes through the ports *G* and *L*, the cavity *M*, the ports *N* and *O*, around the emergency piston (12), into the brake-cylinder. When the pressure in the auxiliary reservoir drops below that in the brake-

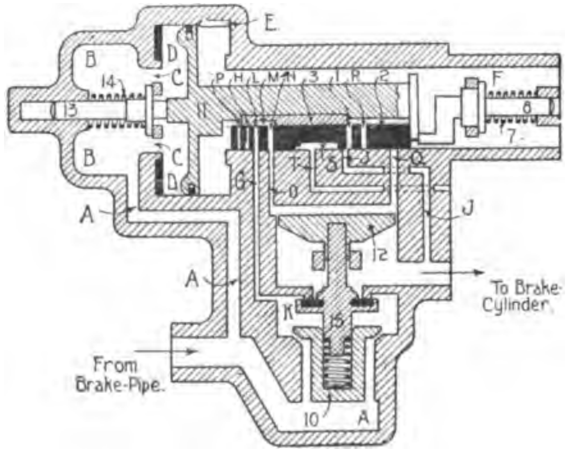


Fig. 48. "K" Triple Valve in Quick-Service Position.

pipe, the check-valve (10) lifts, and air passes from the brake-pipe through the ports mentioned above, into the brake-cylinder. The emergency piston (12) fits loosely in its cylinder and permits air to pass around it without pressing it downward. The ports *G*, *L*, *N*, and *O* are proportioned so that there is no danger of any movement of the emergency piston (12). If this should occur, however, an emergency application would result.

It is readily seen that the action just described will greatly reduce the brake-pipe reduction necessary at the brake-valve, since air is taken into the brake-cylinder from the brake-pipe; also, that a higher cylinder pressure will result than if no air from the brake-pipe passed into the brake-cylinder.

Full-Service Position. In short trains, the volume of air in the brake-pipe is comparatively small. In service applications, air discharges so rapidly by the quick-service feature that an emergency would result were it not automatically prevented by the valve itself. In service applications, if the drop in brake-pipe pressure is more rapid than that in the auxiliary reservoir, then the valve takes the full-service position represented in Fig. 49. It will not, however, take the emergency position, because there is no sudden drop in the brake-pipe pressure. In the full-service position, the pressure behind the piston (11) is such that the graduating spring (14) is slightly compressed. This moves the slide-valve (2) to the left sufficiently to close

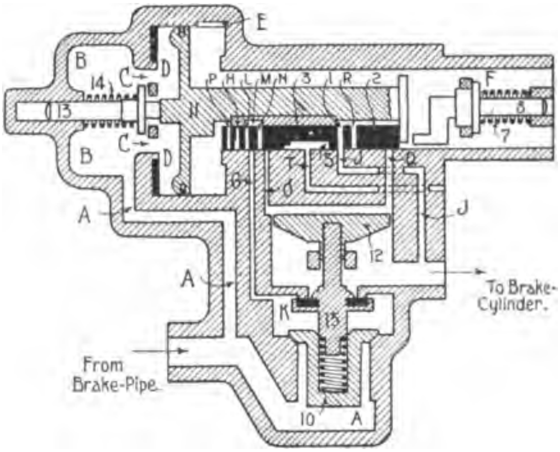


Fig. 49. "K" Triple Valve in Full-Service Position.

the quick-service port *G*, and brings the port *I* into full registration with the port *J*. In this position, no air can enter into the brake-cylinder through the port *G*; but since the ports *I* and *J* are fully open, air is free to pass from the auxiliary reservoir into the brake-cylinder.

Lap Position. When the brake-pipe pressure has become constant after an application has been made, air continues to flow from the auxiliary reservoir through the ports *I* and *J* to the brake-cylinder, until the pressure in the chamber *F* becomes enough less than that in the chamber *D* to cause the piston (11) to move to the right. When the shoulder on the piston (11) strikes the left end of the slide-valve (2), it comes to rest on account of the frictional resistance of the slide-valve. In this position, all ports are closed and the valve is said to be *lapped* (see Fig. 50).

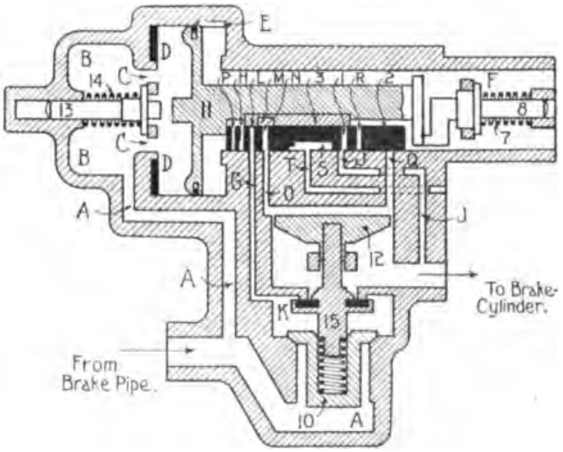


Fig. 50. "K" Triple Valve in Lap Position.

Retarded-Release and Charging Position. It is a well-known fact that in a freight train fitted with standard triples, the cars nearest the engine will release first when the engineer places the brake-valve in release position. This is due, *first*, to the friction of the air in the brake-pipe; and *second*, to the fact, that the auxiliary reservoirs of those brakes which release at the forward end begin to recharge, taking air from the brake-pipe, which reduces the pressure-head. The retarded-release feature overcomes the second point mentioned by taking advantage of the first. The friction of the air in the brake-pipe causes the pressure to build up more rapidly in the chamber *D* of triples at the front end of the train, than it does in those at the rear. When this pressure in the chamber *D* increases sufficiently above that in the auxiliary reservoir to overcome the frictional resistance of the piston, graduating valve, and slide-valve, all three parts move to the right until the piston strikes the retarding-device stem (8), which is held in position by the spring (7). The parts will then be in the position represented in Fig. 47. If, however, the pressure in the chamber *D* builds up faster than the auxiliary reservoir can recharge (as is the case if the triple is near the head of the train), then the piston moves still farther to the right, compressing the retarding-device spring (7) until the parts occupy the position shown in Fig. 51. In this position, the back of the piston (11) is in contact with the slide-valve bush, and, acting as a valve, prevents any air from passing into the auxiliary reservoir through the feed-groove *E*; but the port *P* now registers with the port *G*, permitting air to pass from the chamber *A*—lifting the check-valve (10)—through the ports *G* and *P*, into the auxiliary reservoir. By this latter route, the auxiliary reservoir is recharged only about half as fast as it would be if charged through the feed-groove *E*. As the pressure increases in the auxiliary reservoir and becomes nearly equal to that in the chamber *D*, the retarding-device spring (7) overcomes the friction of the piston, slide-valve, and graduating valve, and moves them to the left to the position shown in Fig. 47. After this, recharging continues through the feed-groove *E* until the pressures are equalized. In the retarded-release position, the exhaust

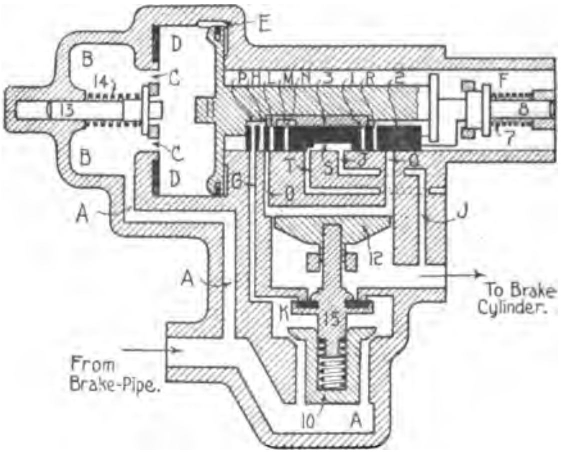


Fig. 51. "K" Triple Valve in Retarded-Release Position.

cavity S connects the port J with the exhaust port T, and the air in the brake-cylinder is discharged into the atmosphere. The discharge is very slow, however, since the small extension of the cavity S (see Fig. 46) is over the port T. This is the retarded-release feature, and affects about the first thirty cars in the train. Finally, when the valve takes the position shown in Fig. 47, the cavity S completely covers the port T, and a free discharge of air from the brake-cylinder occurs.

Emergency Position. This position is shown in Fig. 52. The operation of the "K" triple valve in emergency applications is the same as that of the standard automatic quick-action triple. Quick action is produced by a sudden drop in the brake-pipe pressure.

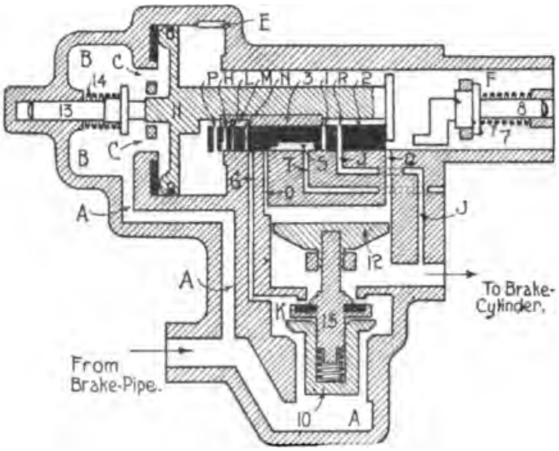


Fig. 52. "K" Triple Valve in Emergency Position.

NEW YORK AIR-BRAKE SYSTEM

The principle of action of the New York Air-Brake is precisely the same as that of the Westinghouse Air-Brake. The New York system is composed of the air-compressor, main reservoir, pump-governor, engineer's brake-valve, brake-pipe, triple valve, auxiliary reservoir, brake-cylinder, and pressure-retaining valve, which are the principal parts and are very similar to those used in the Westinghouse system. The only parts which need special explanation are the air-pump, engineer's brake-valve, and the triple valve.

New York Air-Pump. The New York Air-Pump is a duplex pump, and is built in two sizes. The larger size is shown in section in

Fig. 53. On the lower part are located the steam cylinders, each being 7 inches in diameter. The piston-rods connecting the steam pistons with the air pistons are made hollow for a portion of their length. This hollow portion provides a place for the stem which operates the steam valve. The action of the pump in compressing air is very similar to that of a compound steam engine, the air being compounded instead of steam. The entire valve-gear is very simple. The valves (1) and (2) controlling the action of the pistons are plain D slide-valves. The air-valves are simple check-valves. The operation of the pump in compressing air is as follows:

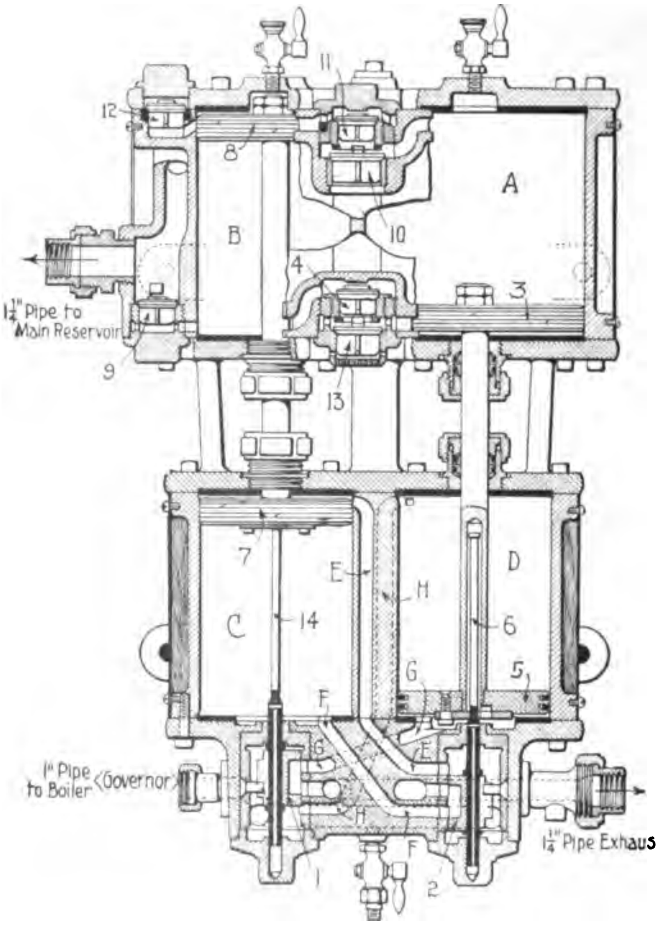


Fig. 53. Section of New York Air-Pump.

Each air cylinder fills with free air at every stroke. The pistons of one side rest while those on the other side are in motion. The valve on one side controls the supply of steam to the opposite side. In the position of the pistons shown in Fig. 53, the piston (3) has completed its stroke, and has forced the air in the cylinder *A* through the air-valve (4) into the cylinder *B* at about 40 pounds' pressure. The plate on the piston (5) has come in contact with the shoulder on the valve-stem (6), and moved the steam valve (2) to the position shown. This opens the port *E*, and steam is permitted to act on the top of the piston (7), forcing it downward. The steam below the piston (7) passes out through the port *F* into the exhaust pipe. As the piston (7) descends, the piston (8) is pulled downward, forcing the partially compressed air in the cylinder *B* out through the air-valve (9) into the main reservoir.

As the piston (8) descends, air at atmospheric pressure enters through the air-valves (10) and (11) and fills the space above the piston (8). In the same way, the cylinder *A* above the piston (3) is also filled with air entering through the air-valve (10). When the piston (7) reaches the lower end of the cylinder *C*, the valve stem (14) is moved downward and causes the steam valve (1) to uncover the port *G*. Steam is now permitted to act below the piston (5), causing it to rise and force the air above the piston (3) through the valve (11), into the cylinder *B* above the piston (8). As the piston (5) ascends, the steam in the cylinder *D* passes through the port *H* and the cavity in the valve (1), into the exhaust pipe. Air entering through the air-valve (13) fills the cylinder *A* below the piston (3). When the piston (5) reaches its highest point, the head on valve-stem (6) engages with the plate on the piston (5), and lifts the steam valve (2) until the port *F* is uncovered. The piston (7), now being at the bottom of its stroke, is acted on by steam from the port *F*, and is forced upward, discharging the air above the piston (8) through the air-valve (12) into the main reservoir. Air entering through the air-valves (13) and (4) fills the cylinder *B* below the piston (8). In this position, the plate on the piston (7) has lifted the valve-stem (14), causing the steam valve (1) to uncover the port *H*. Steam now acts on the top side of the piston (5) through the port *H*, forcing it downward and completing the cycle.

This type of air-pump is more efficient than the type represented by the nine and one-half inch Westinghouse air-pump, since the air cylinders are proportioned such that three measures of air are compressed for two measures of steam, whereas in the Westinghouse pump only two measures of air are compressed for two measures of steam.

New York Engineer's Brake Valve. The New York engineer's brake-valve performs the same functions as the standard Westinghouse engineer's brake-valve. It is illustrated in Figs. 54, 55, 56, and 57. Fig. 54 is a side view showing the different positions of the handle. Fig. 55 shows a longitudinal section of the valve, a plan of the valve-seat, and the face of the slide-valve. Fig. 56 is a section through the feed-valve as seen from the rear. Fig. 57 is a section through the slide-valve as seen from the front. The action of the valve when in its different positions is described as follows:

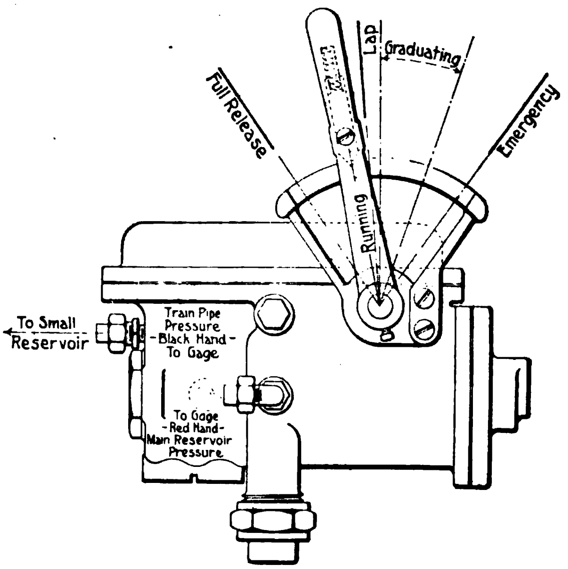

Full Release
Lap
Graduating
Emergency
Running
To Small Reservoir
Train Pipe Pressure -Black Hand- To Gage
To Gage -Red Hand- Main Reservoir Pressure

Fig. 54. Side View of New York Engineer's Brake-Valve, Showing Different Positions of Handle.

Running Position. Fig. 55 shows the position of the parts when the handle of the brake-valve is in running position. The main reservoir is in communication with the chamber *A*; and the brake-pipe, with the chamber *B*. The chamber *C*, to the right of the piston (1), is connected to a small reservoir. When the handle is in running position, the discharge ports *E*, *F*, and *G* in the slide-valve (2) are closed; and air from the main reservoir flows from tne chamber *A*, lifting the feed-valve (3), passing through the port *H* (see Fig. 56), into the chamber *B*, and thence to the brake-pipe.

Service Position. In making service applications, the handle of the brake-valve is placed in one of the *service* or *graduating* notches illustrated in Fig. 54. Placing the handle in this position moves the slide-valve (2) to the right, uncovering the ports *E* and *F*, thus permitting brake-pipe air to escape from the chamber *B* to the atmosphere through the passage *D*. Air continues to be discharged into the atmosphere until the pressure in the brake-pipe and chamber *B* is decreased sufficiently to permit the pressure in the chamber *C*

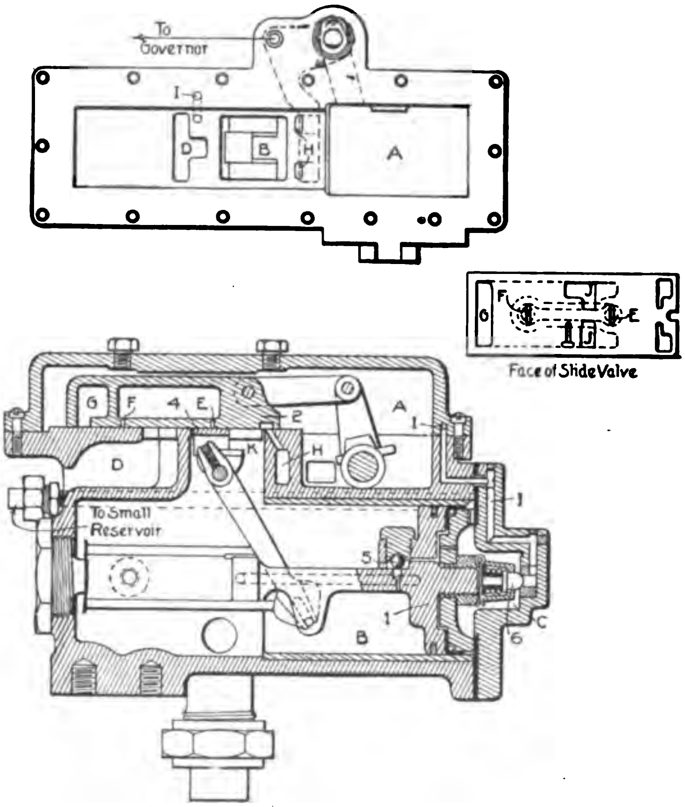


Fig. 55. Longitudinal Section of New York Engineer's Brake-Valve in Running Position, Showing also Plan of Valve-Seat (at top) and Face of Slide-Valve (at right).

(which is in communication with the small reservoir) to move the piston (1) to the left. This movement operates the small slide-valve (4), moving it to the right and closing the port *E*. The small reservoir mentioned above receives its supply of air from the chamber *C*, which, in turn, is supplied with air from the chamber *B*, entering through the ball check-valve (5). For light applications, the first notches are used; and for heavier ones, the last notches. Full-service application is obtained when the handle is placed in the last service notch.

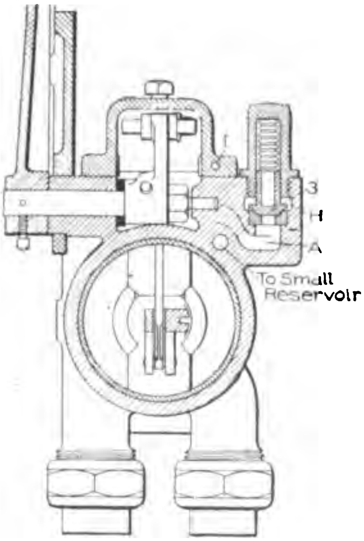


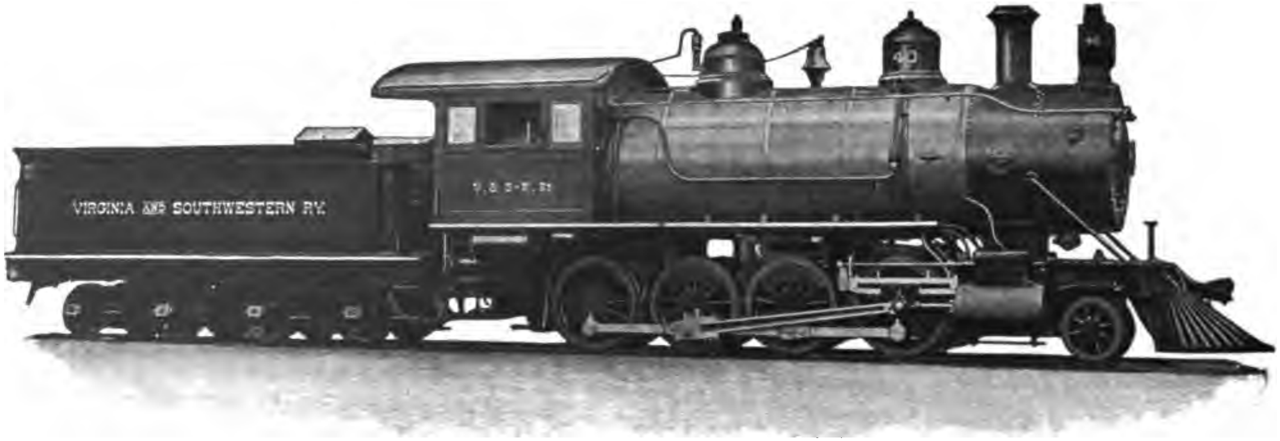
Fig. 56. Section through Feed-Valve of New York Engineer's Brake-Valve, as Seen from Rear.

Emergency Position. When the handle is placed in emergency position, the slide-valve (2) is moved to the right until direct communication is made between the chamber *B* and the exhaust passage *D*. In this position, air flows from the chamber *B* through the port *J* (see Fig. 57) in the slide-valve, out through the port *G*, and into the exhaust passage *D*.

Lap Position. In this position, all communication is closed between the main reservoir and the brake-pipe, and between the brake-pipe and the atmosphere.

Release Position. When the handle is placed in release position, the slide-valve (2) is moved to the extreme left. In this position, the right end of the slide-valve (2) has uncovered the port *K* (see Fig. 55) in the valve-seat, and main-reservoir air flows from the chamber *A* into the chamber *B* and thence to the brake-pipe. At the same time, a small quantity of air in the chamber *C* and the small reservoir discharges through the ports *I* and *J* into the exhaust passage *D*; and brake-pipe pressure, acting on the piston (1), moves it to the position shown in Fig. 55, ready for the next service application. The vent valve (6) controls the passage *I* leading to the valve-seat. The handle of the brake-valve should not remain in this position too long, as there is danger of the auxiliary reservoirs becoming overcharged.

If, after an application, the valve handle is placed in running



CONSOLIDATION FREIGHT LOCOMOTIVE, BALDWIN LOCOMOTIVE WORKS—Total Weight of Engine, 77 Tons position, the brakes will be released; but considerable time will be required, since the air must be supplied to the brake-pipe through the feed-valve (3).

New York Quick-Action Triple Valve. Fig. 58 shows the New York triple valve in section. Its action is quite similar to that of the Westinghouse triple valve. It differs in its quick-action feature, however, in that, when an emergency application is made, no additional brake-cylinder pressure is obtained above that secured in a full-service application. The action of the valve in service and emergency application is as follows:

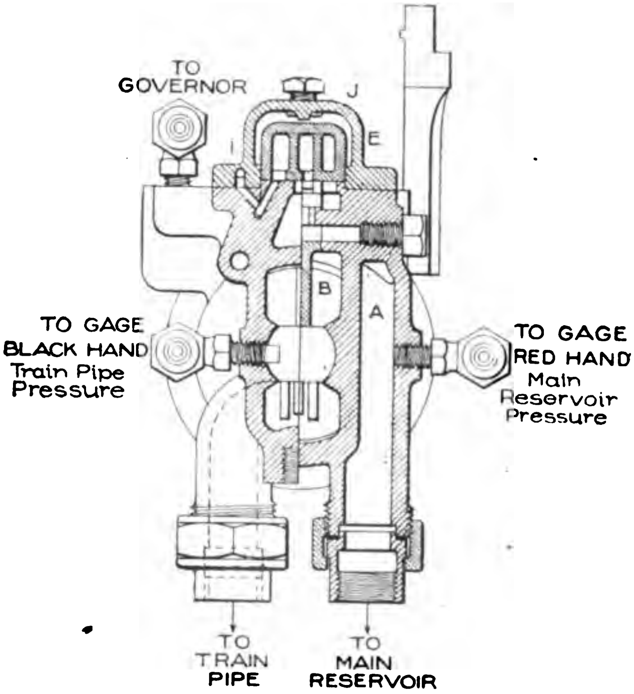

TO GOVERNOR
J
I
E
B
A
TO GAGE BLACK HAND Train Pipe Pressure
TO GAGE RED HAND Main Reservoir Pressure
TO TRAIN PIPE
TO MAIN RESERVOIR

Fig. 57. Section through Slide-Valve of New York Engineer's Brake-Valve, as Seen from Front.

Charging and Release Position. The different parts of the valve are shown in this position in Fig. 58. Air from the brake-pipe enters the chamber A, passes through the ports B and C into the chamber D, through the feed-groove E into the chamber F, and into the auxiliary reservoir. Air continues to flow into the auxiliary reservoir until its pressure is the same as that in the brake-pipe. The head of the piston (1) is made so as to form a cylinder in which the piston (2) moves. Air at brake-pipe pressure enters the chamber *G* through the port *H*. If air-pressure exists in the brake-cylinder when the valve is in this position, it will flow out into the chamber *I* through the port *J*, the cavity *K*, and the port *L*, into the exhaust cavity *M*, to the atmosphere. In this position, air exhausts from the brake-cylinder until the brake is fully released.

Service Position. When the engineer's brake-valve is placed in service position, air is exhausted from the brake-pipe, and the pressure is gradually reduced. The reduced pressure on the left of the piston (1) causes auxiliary-reservoir pressure (on the right) to move it slowly to the left until it strikes the gasket (4). The motion, being slow, permits the air in the chamber *G* to exhaust through the port *H*. In this position, the piston (1) has moved the exhaust valve (3) to the left, closing the exhaust port *J*, and has caused the graduating valve (5) to uncover the port *N*. Air now flows from the auxiliary reservoir, through the port *N*, to the chamber *I*, into the brake-cylinder.

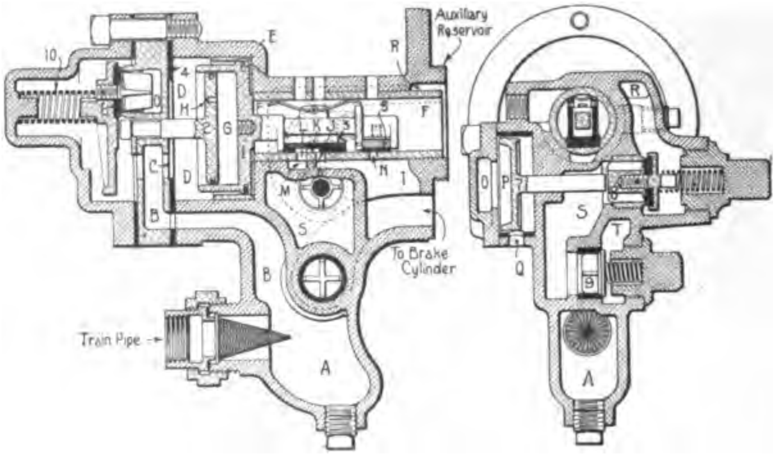


Fig. 58. New York Quick-Action Triple Valve in Charging and Release Position.

Lap Position. If the brake-pipe reduction has not been sufficient to cause full equalization of the auxiliary-reservoir and brake-cylinder pressure, air will continue to flow from the auxiliary reservoir to the brake-cylinder until the pressure on the left of the piston (1) moves it toward the right. This movement of the piston (1) is stopped when the left shoulder on the piston (1) strikes the left end of the exhaust valve (3). In this position, the port J is closed by the slide-valve (3), port N is closed by the graduating valve (5), and the valve is said to be *lapped.*

Emergency Position. The piston (1) has the same movement in both service and emergency positions. The port H is of such size that when the piston (1) moves slowly to the left, as in service applications, the air in the chamber G is forced out without moving the piston (2) from the position shown. If an emergency application is desired, the handle of the engineer's brake-valve is moved at once to emergency position. This causes the brake-pipe pressure to drop very suddenly, and the piston (1) to move to the left so rapidly that the air in the chamber G cannot discharge through the port H fast enough to prevent the piston (2) from being disturbed. The result is that the piston (2) is moved to the left. This movement causes the valve (6) to be momentarily pushed from its seat by the stem of the piston (2). This allows air from the brake-pipe to enter the cavity O, flow around the side to the chamber P, and escape to the atmosphere through the port Q. The air now in the chamber P forces the piston (7) to the right, which unseats the valve (8), and permits air from the auxiliary reservoir to flow through the port R, the valve (8), the chamber S, the check-valve (9), and the chamber T, into the chamber I, and thence to the brake-cylinder. As the last-mentioned passages are very large, full braking pressure is obtained instantaneously. While the action just described is going on, air from the chamber G is being discharged through the port H. When it is entirely exhausted, the spring (10) seats the valve (6), and all parts occupy positions as described under *service position.*

FOUNDATION BRAKE-GEAR

The foundation brake-gear includes all levers, rods, beams, pins, etc., which serve to transmit the braking force from the piston of the brake-cylinder to the brake-shoes. It is important that all longitudinal rods should be parallel with the center line of the car when the brakes are fully applied. The brake-beams should be hung in such a manner that they will always be the same distance above the rail, the reason being that this practice reduces the chance for flat wheels, since the piston travel is not affected by the loading or unloading of the car.

The rods and levers should be designed so that they will move in the same direction when the brakes are applied by hand as when by air. The levers should stand approximately at right angles to the rods when the brakes are set.

A number of different systems of rods and levers have been used by different railroad companies, with varying degrees of success. The systems adopted by the Master Car-Builders' Association are diagrammatically shown in Fig. 59. The four cases shown represent two general systems—those where the brake-shoes are *hung inside*, between the truck wheels, and those where they are *hung outside*. Freight-cars are generally fitted with the brake-shoes hung inside, while passenger cars usually have the brake-shoes hung outside. In the first two systems (*A* and *B*), the brake can be applied by hand from only one end of the car; while in the other two systems (*C* and *D*) the brake can be operated by hand from either end. In applying the brake by hand in any case, the coil spring in the brake-cylinder offers no resistance, since the push rod has no pin connection to the piston-rod. The piston-rod of the brake-cylinder is hollow. When the brake is operated by hand, the push rod slides outward in the hollow rod without moving the piston. A detailed description of the opera-

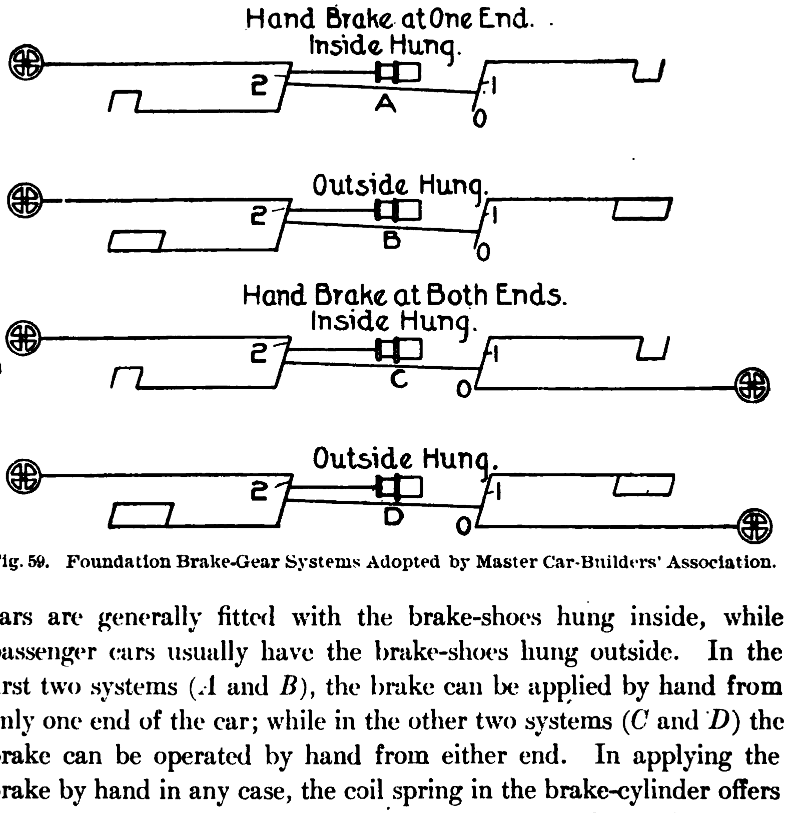


Fig. 59. Foundation Brake-Gear Systems Adopted by Master Car-Builders' Association.

tion of the four systems shown is not thought necessary. One or two points, however, might assist to a clearer understanding of them. The lower end of the lever (1) in the systems *A* and *B* is fixed at *O*. The lower end of the lever (1) in the systems *C* and *D* is held by a stop at *O*, and cannot move to the left, but is free to move to the right, when the brake is operated by hand from the right-hand end of the car. The lever (2) in all four systems has no fixed points. In all cases, the arrangement is such that no brake-shoe will press against its wheel with any great force until all brake-shoes are held firmly against their respective wheels, and all shoes press against the wheels with an equal force.

Fig. 60, with all parts named, shows the application of the system *A* to a freight-car. No explanation is needed.

Leverage. It is a well-known principle in Mechanics, that the greater the weight on a car wheel, the greater the brake-shoe pressure on that wheel necessary to cause it to slide on the track. For this reason, in designing the brake-rigging for a car, the light, or unloaded, weight of the car is the basis of all calculations. If the loaded weight of the car were used in calculating the levers, the proportions would be such that if the brakes were applied

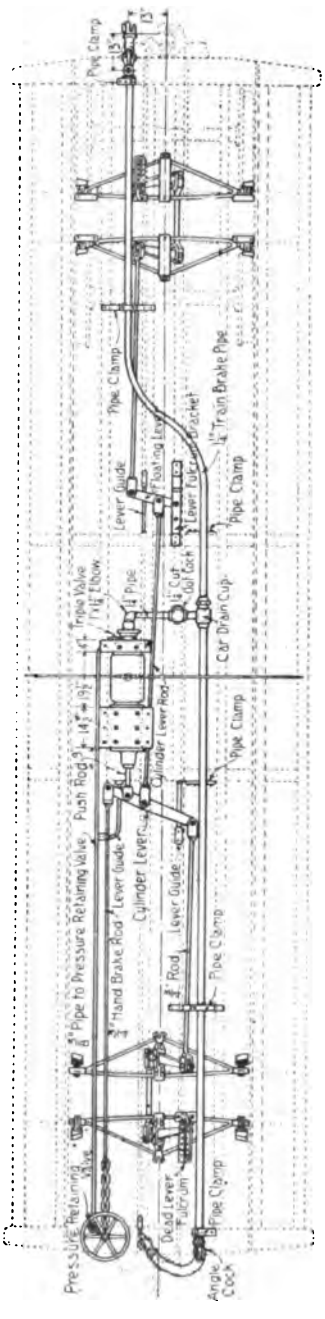
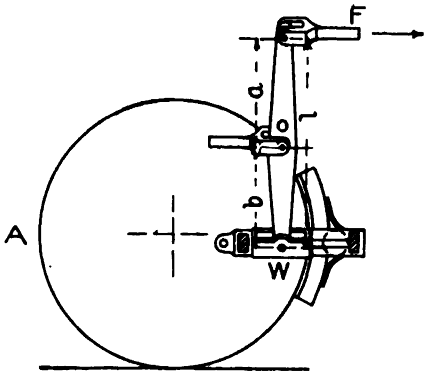


Fig. 60. Application, to a Freight Car, of Inside-Hung Brake-Gear System Shown at *A* in Fig. 59.



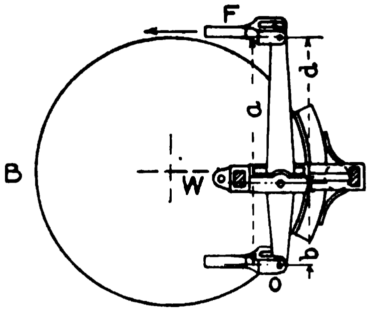
$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad l = a + b;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W \times l}{F + W};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times l}{F + W}.$$

FULCRUM BETWEEN APPLIED AND DELIVERED FORCES.



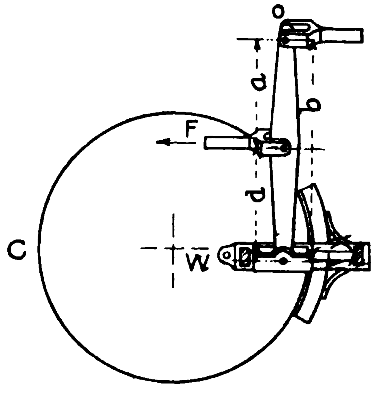
$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad a = b + d;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W \times d}{W - F};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times d}{W - F}.$$

DELIVERED FORCE BETWEEN FULCRUM AND APPLIED FORCE.



$$W = \frac{F \times a}{b};$$

$$F = \frac{W \times b}{a}; \quad b = a + d;$$

$$a = \frac{W \times b}{F}; \text{ or, } a = \frac{W - d}{F - W};$$

$$b = \frac{F \times a}{W}; \text{ or, } b = \frac{F \times d}{F - W}.$$

APPLIED FORCE BETWEEN FULCRUM AND DELIVERED FORCE.

Fig. 61. Illustrating Application of Principle of Moments to Levers in Brake Systems.

when the car was unloaded, the wheels would slide. In order to prevent any chance arising of having flat spots worn on the wheels, due to the wheels sliding on the track, the following percentages of light weights on the wheels are usually employed in determining the brake-shoe pressure:

Passenger cars	90 per cent.
Freight cars	70 per cent.
Tenders	100 per cent.
Locomotive drivers	75 per cent (of weight upon the drivers).
Locomotive truck	75 per cent (of weight upon the truck).

These percentages are sometimes changed to meet special conditions which arise.

In calculating the brake-shoe pressure of any car, one must know three things: *First,* the diameter of the brake-cylinder and its maximum pressure; *second,* the sizes and positions of all levers in the system; and *third,* a knowledge of the theorem of moments as used in Mechanics.

The principle or theorem of moments may be stated thus: *The product of the force applied at one pin and its perpendicular distance from the fulcrum pin, is equal to the product of the force delivered at the other pin and its perpendicular distance from the fulcrum pin.* This principle has been applied to the three different classes of levers; and the forces and distances have been worked out, and are shown in Fig. 61. The chief difficulty the beginner encounters is in locating the fulcrum pin.. In A, B, and C (Fig. 61), the fulcrum pin is located at O, the force applied is F, and the force delivered is W. In any case, if the pull F on the lever is known, the brake-shoe pressure W can be determined.

Fig. 62 represents diagrammatically the scheme of levers and rods commonly used on freight-cars. All distances of rods from the center line of the car are taken when the levers are at right angles to it. The brake-cylinder is 8 inches in diameter, and has an area of about 50 square inches. If the maximum brake-cylinder pressure in emergency applications is 60 pounds, the total pressure delivered to the push rod would be 50 × 60 = 3,000 pounds. This 3,000 pounds is transmitted to the lever E at the pin (1). The lever E is of the class shown in B (Fig. 61), and its fulcrum is at the pin (3). Applying the formula gives 4,500 pounds delivered at the pin (2). This 4,500 pounds is

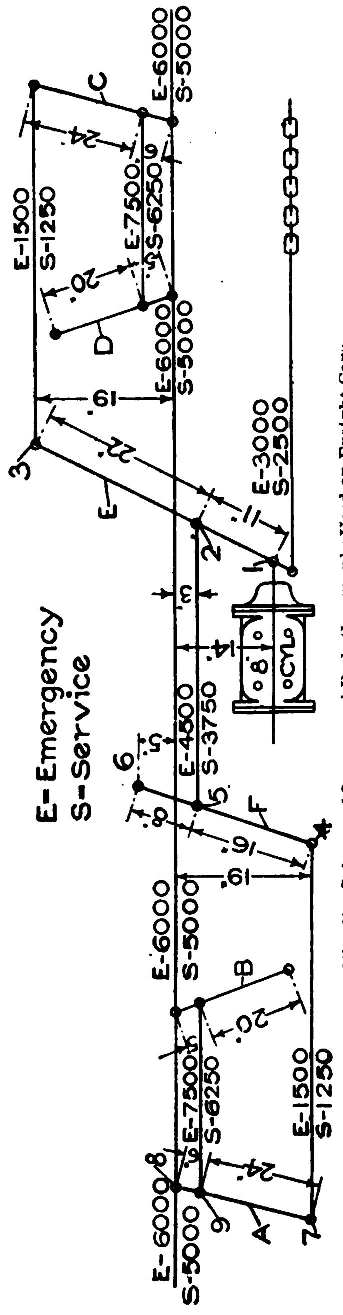


Fig. 62. Scheme of Levers and Rods Commonly Used on Freight-Cars.

transmitted to the lever *F*, which is of the class shown in *C* (Fig. 61), and its fulcrum is at the pin (6). Applying the formula gives 1,500 pounds delivered at the pin (4). This 1,500 pounds is transmitted to the lever *A*, which is of the class shown in *A* (Fig. 61), and its fulcrum is at the pin (9). Applying the formula gives 6,000 pounds delivered to the brake-beam at the pin (8). In a similar manner the other brake-beam pressures can be determined. In the figure, the calculation has been carried through for both service and emergency applications.

It is seen that 6,000 pounds is transmitted to the middle of each of the four brake-beams. Each brake-shoe will then receive a pressure of 3,000 pounds. Since there are eight wheels, the total braking pressure will be 8 × 3,000 = 24,000 pounds. This total braking pressure must not exceed 70 per cent of the unloaded weight of the car.

Automatic Slack-Adjuster. Full braking pressure will be secured as long as the maximum allowable brake-cylinder pressure can be maintained. Since the brake-cylinder pressure depends upon the length of stroke of the piston, it follows that the stroke of the piston should be kept as nearly constant as possible. The greater the stroke, the less the pressure. The stroke of the piston should be kept at about 8 inches. As the brake-shoes and various connections wear, the stroke of the piston is increased, and the pressure with which the shoes are forced against the wheels is decreased. In order to compensate for this wear, some means must be provided for taking up the slack. This is done in one of two ways, either by changing the fulcrum pin of the dead lever (see Fig. 60) or by using the *automatic slack-adjuster*. The first method of adjustment is the one most commonly used, and is necessarily very coarsely graded. The *automatic slack-adjuster*, when used at all, is usually fitted to the passenger-car equipment.

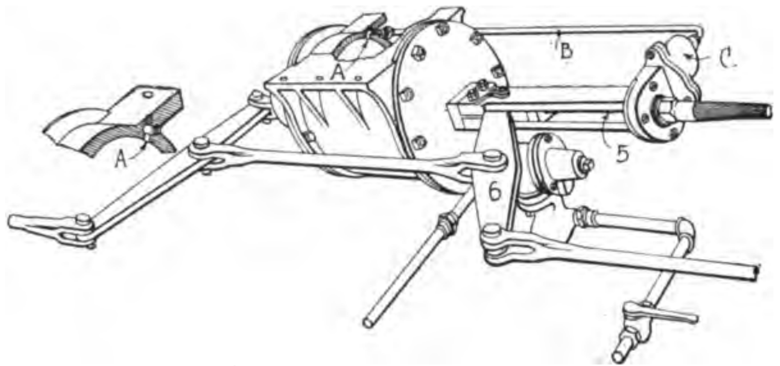


Fig. 63. Automatic Slack-Adjuster.

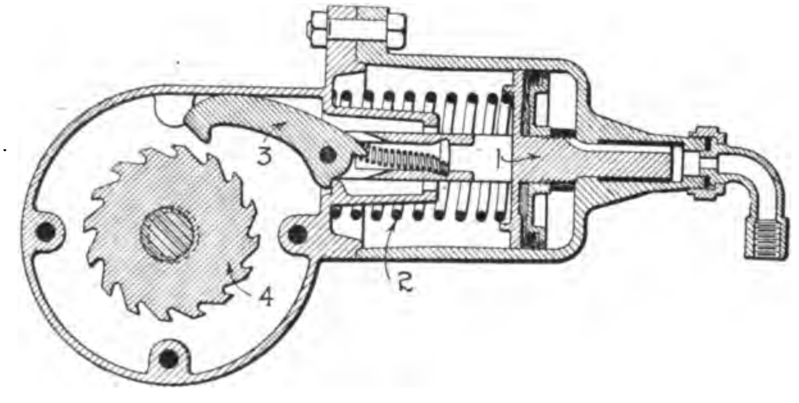


Fig. 64. Part Sectional View of Automatic Slack-Adjuster.

The *automatic slack-adjuster*, illustrated in Figs. 63 and 64, is manufactured by the Westinghouse Air-Brake Company. The purpose of the apparatus is to maintain a constant, predetermined piston travel. The brake-cylinder piston acts as a valve to control the admission and release of air to the pipe *B* through the port *A*. Whenever the stroke of the brake-cylinder piston is so great that the port *A* is passed by the piston, air from the cylinder enters the port *A* into the pipe *B*, and enters the cylinder *C*, which is shown in section in Fig. 64. The air entering the small cylinder acts on the piston (1) forcing it to the left, compressing the spring (2), and causing the small pawl (3) to engage the ratchet wheel (4). When the brake is released, the brake-cylinder piston returns, and air in the small cylinder *C* escapes to the atmosphere through the pipe *B* and the port *A*, thus permitting the spring (2) to force the piston (1) to its normal position. In so doing, the pawl (3) turns the ratchet wheel (4) on the screw (5), and thereby draws the fulcrum end of the lever (6) slightly nearer the slack-adjuster cylinder *C*. Each operation of the piston (1), as just described, reduces the brake-cylinder piston travel about $\frac{1}{32}$ of an inch. When the piston (1) is in its normal position, the outer end of the pawl (3) is lifted, permitting the screw (5) to be turned by hand.

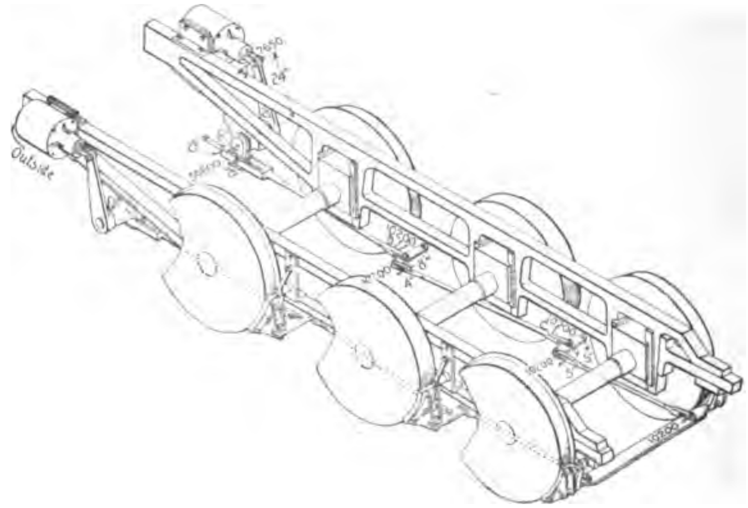


Fig. 65. Outside Equalized Driver-Brake for Locomotives.

Locomotive-Driver Brakes. The brakes are applied to the drivers of a locomotive in two general ways—by the *outside equalized* system, as illustrated in Fig. 65; and by *cams*, as shown in Fig. 66. The former scheme has practically replaced the latter because of its

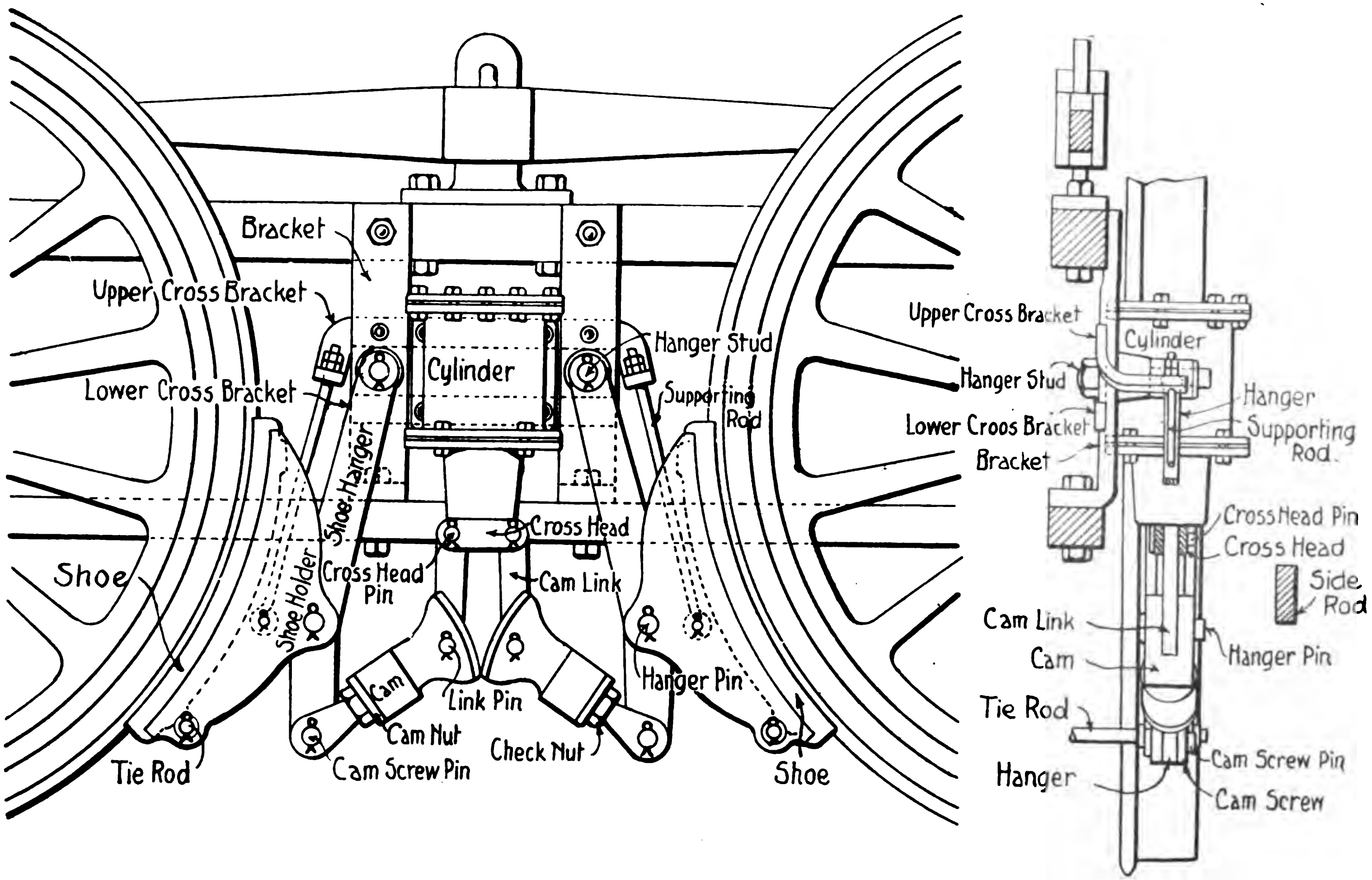


Fig. 66. Cam Driver-Brake for Locomotives.

being simpler in design and adjustment. The brake-cylinders and auxiliary reservoirs used on locomotives are usually proportioned so that the pressure in the brake-cylinder will equalize at 50 pounds. In the system shown in Fig. 65, the levers are constructed so that each wheel receives the same braking pressure. If the brake-cylinder is 14 inches in diameter and the cylinder pressure is 50 pounds, the pressure delivered at the pin *A* is about 7,650 pounds, while that on each wheel is 10,200 pounds. These values, of course, are different for different locomotives. The stroke of the piston is regulated by the adjusting mechanism at *B*.

The action of the cam driver-brake is shown in Fig. 66. When air is admitted to the brake-cylinder, the piston is forced downward. This action pushes down the crosshead cams, which force the brake-shoes against the drivers. The piston travel is controlled by adjusting the cam nut on each cam.

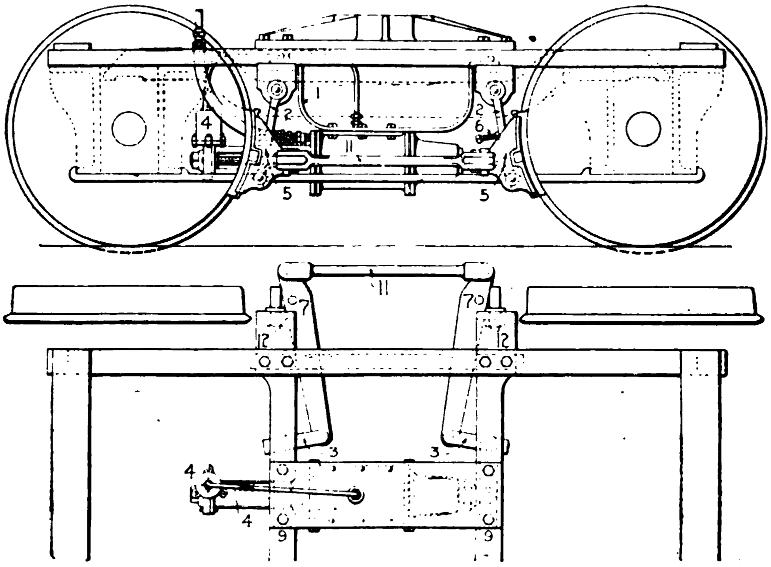


Fig. 67. Locomotive-Truck Brake.

Locomotive-Truck Brake. In certain types of locomotives, a considerable proportion of the weight of the locomotive is carried on the truck. It follows, that in order to develop the full braking power of the locomotive, a well-designed truck brake should be provided. The type of brake shown in Fig. 67 is frequently used. It is fitted with an automatic slack-adjuster. This feature is not so important here as on the car equipment.

WESTINGHOUSE TRAIN AIR-SIGNAL SYSTEM

The train signal system is very essential in maintaining fast schedules with passenger trains. Its object is to furnish a means of communication between the trainmen and enginemen. It is made up of the following principal parts:

1. A ¾-inch *signal pipe,* which extends throughout the length of the train, being connected between cars by flexible hose and suitable couplings.
2. A *reducing valve,* which is located on the engine, and which feeds air from the main reservoir into the signal pipe at 40 pounds' pressure.
3. A *signal valve and whistle,* located in the cab and connected to the signal pipe.
4. A *car discharge valve,* located on each car, which is connected to the signal pipe.

The action of the signal system is automatic. If an accident happens to the train, which breaks the signal pipe, the pressure in the signal pipe is reduced, and the whistle in the cab blows a blast. The trainmen signal the enginemen by opening the card ischarge valve, which reduces the pressure in the signal pipe. This reduction of pressure in the signal pipe operates the signal valve in the cab, which admits air to the whistle. The operation of the various parts is as follows:

Reducing Valve. A section through the reducing valve is shown in Fig. 68. This valve is located in a suitable place on the locomotive. Its purpose is to receive air from the main reservoir and feed it into the signal pipe, maintaining a pressure of 40 pounds. When no air is in the system, the parts occupy the position shown. When air is admitted from the main reservoir, it flows through the passage *A* and the supply valve (1), into the chamber *B* and out through the port *C* into the main signal pipe. When the air in the main signal pipe attains

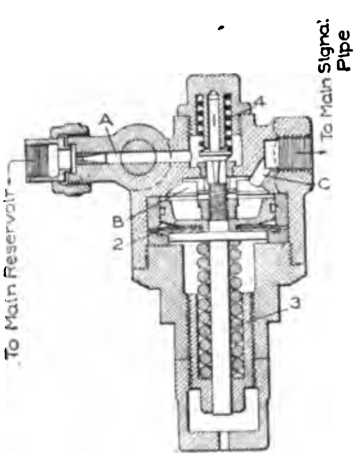


Fig. 68. Section through Reducing Valve in Westinghouse Air-Signal System.

a pressure of 40 pounds, the pressure in the chamber *B*, acting on the piston (2), forces it downward, compressing the spring (3). This permits the spring (4) to close the supply valve (1). No more air can then enter the signal pipe until its pressure becomes reduced so that the spring (3) will force the piston (2) upward and lift the supply valve (1).

Signal Valve. The signal valve controls the supply of air to the whistle. Whenever a reduction of air-pressure occurs in the signal pipe, the signal valve admits air to the whistle. A section of the valve is shown in Fig. 69. The two compartments *A* and *B* are divided by the diaphragm (1) to which is attached the stem (2). The stem (2) is milled triangular in section from the lower end to the peripheral groove (3). Above the groove (3), the stem (2) fits the bush (4) snugly. The lower end of the stem (2) acts as a valve on the seat (5). Air enters the signal valve from the signal pipe, through the passage *C*. It then passes through the small port *D* into the chamber *A*, and through the passage *E*, around the stem (2), into the chamber *B*. This charges the chambers *A* and *B* to signal-pipe pressure. A sudden reduction in signal-pipe pressure reduces the pressure in the chamber *A*; and the diaphragm (1), acted on by the pressure in the chamber *B*, rises, lifting the stem (2) and momentarily permitting air to pass

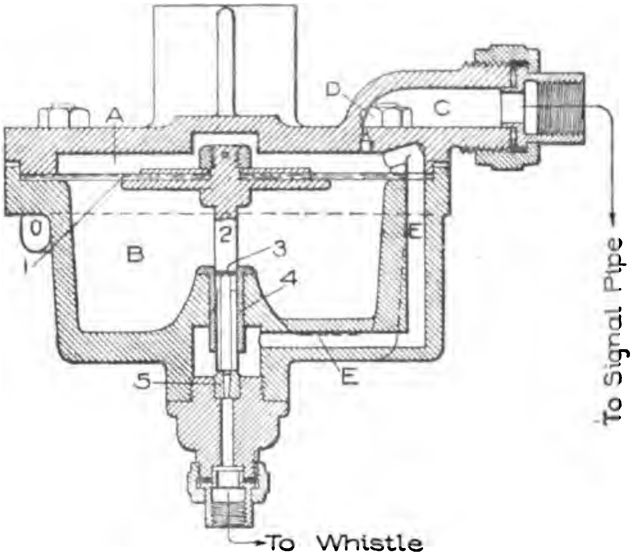


Fig. 69. Section through Signal Valve in Westinghouse Air-Signal System.

from the signal pipe to the whistle. The resulting blast of the whistle is a signal to the enginemen. This same reduction of pressure in the signal pipe causes the reducing valve to recharge the system. The pressure in the chambers *A* and *B* equalizes quickly, and the lower end of the stem (2) returns to its seat.

Car Discharge Valve. The discharge valve is usually located outside the car, above the door, in such a position that the signal cord passing through the car can easily be fastened to the small lever of the valve.

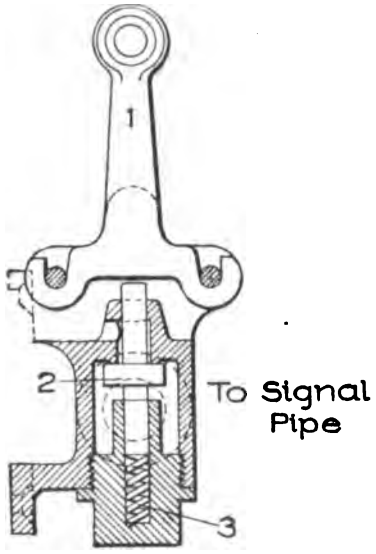


Fig. 70. Section through Car Discharge Valve in Westinghouse Air-Signal System.

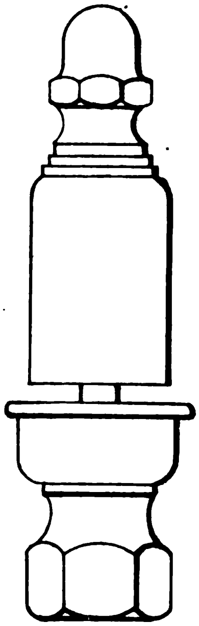


Fig. 71. Signal Whistle in Westinghouse Air-Signal System.

Fig. 70 is a section of the valve. The valve is connected to a branch pipe which extends from the signal pipe. The signal cord is connected to the eye in lever (1). Each pull in the signal cord causes the lever (1) to open the check-valve (2), permitting air to escape from the signal pipe. This causes a reduction in the signal pipe, which, in turn, causes the whistle to blow as previously described. The spring (3) closes the valve (2) when the signal cord is not held.

For the successful operation of the signal system, the signal pipe must be perfectly tight. Care must be exercised in using the car discharge valve, that sufficient time is permitted to elapse between successive discharges.

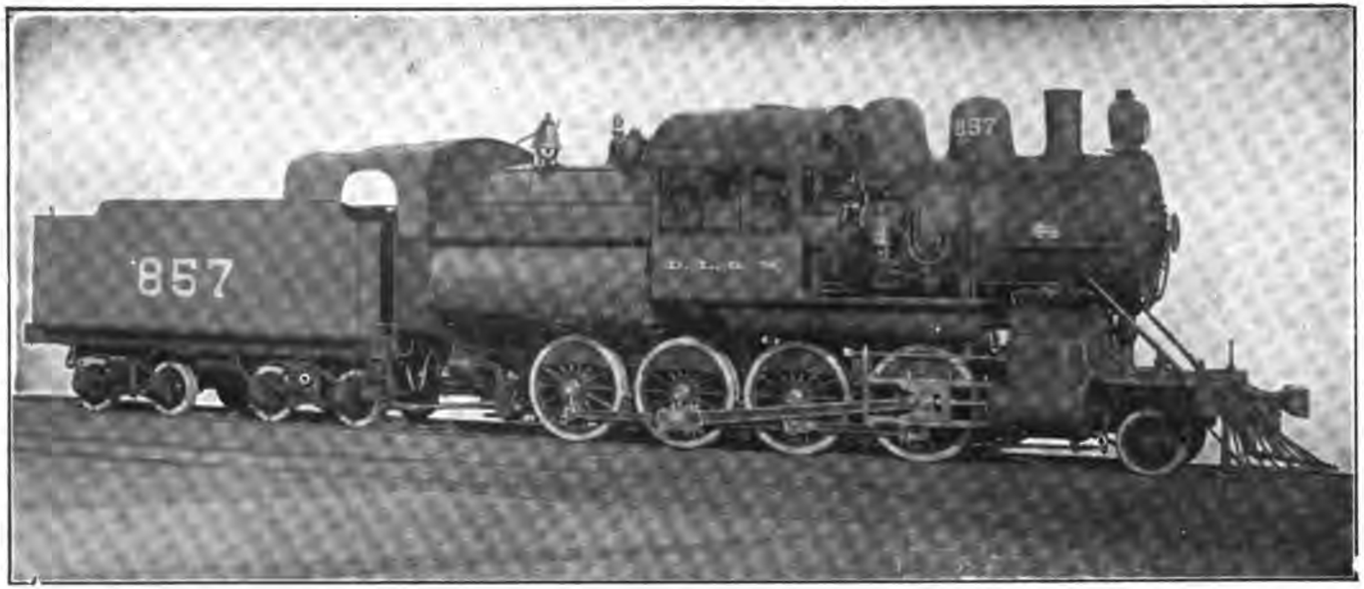
SPECIAL INSTRUCTIONS IN USE AND CARE OF AIR-BRAKE EQUIPMENT

Train Inspection. When a train is made up at a terminal, the air hose should all be coupled, and the angle-cocks all opened except the one at the rear end of the last car. The brake-pipe should then be charged to about 40 pounds,in order that the inspector may examine for leaks. When the brake-pipe has been fully charged, the engineer should apply the brake by making a light reduction in the brake-pipe, which should then be followed by a full-service application. He should note the time required in making these reductions, in order to be assured that all pistons are moved past the leakage groove when the train is out upon the road. The engineer, after making the full reduction, should leave his brake-valve in lap position until the inspector has examined the brake under every car. It should be the duty of the engineer to see that the brake equipment on the locomotive is in proper working order.

Running Test. In passenger service, when a locomotive has been changed or a train made up, the engineer should make a running test within one mile of the station, as follows: A brake-pipe reduction of about 5 pounds should be made. If the brakes are felt to be applying, and the time of the discharge is proportional to the number of cars in the train, the engineer will conclude that the brake is in proper working order. It is well, also, to make this test on approaching hazardous places.

Service Applications. In making a service application of the brakes, the first reduction should be about 5 pounds on a train of 30 cars or less, and about 7 pounds on a train exceeding 30 cars. This will insure the travel of all pistons beyond the leakage groove. Subsequent reductions of from two to three pounds can be made, to increase the braking power, if desired. A reduction of 25 to 30 pounds will make a full-service application. This should seldom be made, as it requires some time to recharge the system and release the brakes.

In stopping a passenger train, two applications should be used: the first should reduce the speed of the train to about 8 miles an hour when the train is within two or three car lengths of the point at which the train is to be stopped. Moving the brake-valve handle to release position for only sufficient time to release all brakes, then returning it



Freight Engine, 2-8-0 Type, Built at the Schenectady Works. American Locomotive Company.

to lap position, will make it possible for a second light application to stop the train. Just before all stops of passenger trains, except exact-position stops at water stations and coal chutes, the brakes should be released to avoid shocks to passengers. This release should be made on the last revolution of the drivers. If it should be made too soon, and the train keep on moving, the engineer's brake-valve should be moved to service position until the train stops

In making stops of freight trains, the best practice is to shut off the steam, and allow the slack to run in before applying the brakes. The stop should be made with one application of the brakes. After the first reduction is made, if there are any leaks in the brake-pipe, the braking force will be increased, and any subsequent reduction should be made less, in order to make up for these leaks.

In stopping a long freight train at water stations and coal chutes, it is best to stop short of the place, cut off, and run up with the locomotive alone.

On a freight train, where the locomotive is not equipped with the straight air-brake, the brakes should not be released when the speed of the train is 10 miles per hour or less. If this is done, the brakes in the front of the train will release, and, as the slack runs out, the train may part. If the locomotive is equipped with straight air, the train brakes can be released after the locomotive brakes are set, without danger of parting the train. This can also be accomplished by the use of the Westinghouse "E T" equipment.

Emergency Applications. The emergency application should never be used, except in case of an emergency. If the necessity arises, an emergency application may be made after a service reduction of about 15 pounds.

In case an emergency is caused by the train parting, hose bursting, or the conductor's valve being opened, the engineer should place his valve on *lap*, in order to save the main-reservoir air.

Use of Sand. The use of sand increases the braking power of a train, and should be made in emergency stops. If sand is used in service stops, it should be applied some time before the brakes are applied, in order to have sand under the entire train. If, for any reason, the wheels should skid, do not apply the sand, as it will produce flat spots on the wheels.

Pressure-Retaining Valve. In holding trains on grades, a part or all of the retaining valves are set to hold 15 pounds in the brake-cylinder. If only part are set, those in the front of the train should be used.

Backing Up Trains. In backing up freight trains, the train should be stopped by the hand-brakes on the leading end of the train, for the reason that if air were used, the brakes would apply on the cars near the engine and the leading cars might cause a break-in-two.

In backing up a passenger train, where the train is controlled by a man on the leading car by means of an angle-cock, the engineer's valve should be in running position. This gives the man on the rear of the train full control of the brakes. As soon as the engineer feels the brake apply, he should place his valve on *lap*.

Double-Heading. When two or more locomotives are coupled in the same train, the brakes are operated by the leading locomotive. The cut-out cocks in the brake-pipe just below the engineer's valve on all locomotives but the first, should be closed. The pumps on all engines should be kept running.

Conductor's Brake-Valve. A conductor's brake-valve is located on each passenger car. The purpose of this valve is that the conductor may stop the train in case of emergency; if the engineer's brake-valve should fail to operate, he may signal the conductor to apply the brakes by opening the valve.

Use of Angle-Cocks. In setting a car out of a train, first release the brakes, then close the angle-cock on both sides of the hose to be disconnected, and finally disconnect the hose by hand. Before leaving a car on the side track, the air-brakes should first be released by opening the release valve on the auxiliary reservoir; and if the car is on a grade, the hand-brake should be set.

The angle-cock should not be opened on the head end of a train while the locomotive is detached. When connecting a locomotive to a train that is already charged with air, the angle-cock at the rear of the tender should be opened first, to allow the hose to become charged and thus prevent a slight reduction in the brake-pipe, which might set the brakes. All angle-cocks upon charged brake-pipes should be opened slowly.

Cutting Out Brakes. If the brake equipment on any car is defective, it may be cut out by closing the cut-out cock in the branch pipe leading from the brake-pipe to the triple valve. The release valve on the auxiliary reservoir should be opened to discharge the air. Never more than three cars with their brakes cut out should be placed together in a train, on account of the emergency feature being unable to skip more than this number.

Air-Pump. The air-pump should be run slowly with the drain-cocks open until the steam cylinder becomes warm and sufficient air-pressure has been attained to cushion the air, after which time the throttle may be fully opened. The lubricator should be in operation as soon as possible after starting, and the swab on the piston-rod should be kept well oiled. The air cylinder should receive oil each trip. Valve oil should be used, and it should be inserted through the oil-cup provided for that purpose, and not through the air strainer.

Engineer's Brake-Valve. With the handle in running position, the main-reservoir pressure should be maintained at 90 pounds, and the brake-pipe at 70 pounds. This requires that the springs in the pump-governor and feed-valve must be carefully adjusted, and that no leaks exist between ports in the rotary valve. The rotary valve should be cleaned and oiled when necessary; and if leaks exist, the valve should be scraped to a fit.

Triple Valve and Brake-Cylinders. These should receive an occasional cleaning and oiling, in order that they may be relied upon to fulfil their function. In cleaning the cylinder, special attention should be given to removing any deposit in the leakage groove. The walls of the cylinder should be coated with suitable oil or grease, and all bolts in the cylinder-head and follower should be kept tight.

In cleaning the triple valve, a common practice is to place the removable parts in kerosene until the other parts and the brake-cylinder have been cleaned. The parts are then removed, cleaned, oiled, and replaced. Special care should be given to the slide-valve and its seat, and to the graduating valve. All lint should be removed before replacing the parts. The piston packing-ring should never be removed, except for renewing. A few drops of oil is all that is necessary for lubricating the entire triple valve. No oil should be permitted to get upon the gaskets or rubber-seated valve. The graduating-valve and check-valve springs should be examined, and, if necessary, renewed.

AIR-BRAKES AS APPLIED TO ELECTRIC CARS

That electric street-cars and interurban cars should be equipped with reliable and efficient braking apparatus, is a well-established fact. It is emphasized by the frequent accidents which occur on roads where poorly constructed braking appliances are used. The modern electric car is several times heavier than cars used a decade ago, and speeds have increased remarkably, yet we frequently find cars fitted with braking apparatus but little better than that used in the days of the horse-car. Of recent years, the most progressive roads have given much attention to the construction of equipment, in order to insure the safety of their passengers, and, as a result, braking appliances have been greatly improved.

The hand-brake was the first form of brake used on electric cars, and is still quite largely used. It is found to-day on most cars fitted with air-brakes, to be used in case of necessity. The early forms of the hand-brake consisted of a brake-staff located at either end of the car, having a chain connected to the lower end of the staff. As the handle is turned, the chain is wound up on the staff, and the resulting motion actuates the rods and levers which bring the brake-shoes in contact with the wheels. An improved form of brake-staff is that shown in Fig. 72. Here the winding drum takes the form of a spiral cam. In operation, the slack in the chain is quickly taken up and a very great braking pressure can be obtained.

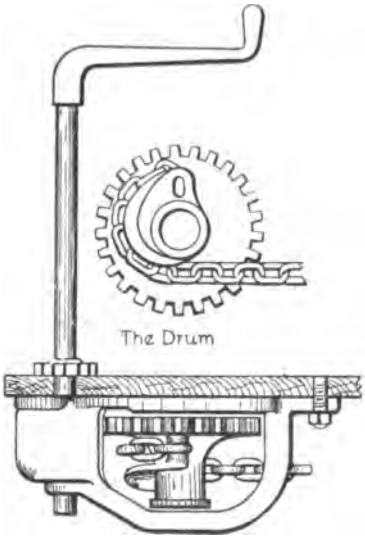


Fig. 72. Hand-Brake for Electric Cars.

The first form of air-brake installed on electric cars was the *Straight Air-Brake* system. It is largely used to-day, as is also the *Automatic Air-Brake* system. The Straight Air-Brake system is usually found on trains of not more than two cars in length. Since electric roads do not at this time interchange cars to any great extent, there is no very great necessity for interchangeable air-brake apparatus. As a result, there are a number of different types of air-brake apparatus found in use on electric cars. All operate more or less upon the same general principles.

As the space allotted to this subject is limited, only one system will be described, namely—the Westinghouse system. This system is chosen, since it represents in a general way other systems in use on many roads.

Westinghouse Straight Air-Brake. The action of the Westinghouse Straight Air-Brake system for electric cars is the same as that already described for steam roads (see page 11).

The system is composed of the following principal parts:

1. An *air-compressor*, operated by an electric motor, to provide compressed air.
2. A *governor* which automatically controls the action of the compressor, thereby maintaining the supply of compressed air at the proper pressure.
3. A *system of wiring*, with the proper switches, fuse-boxes, etc., which connect the trolley current to the governor and compressor.
4. A *large reservoir* in which compressed air is stored.
5. A *brake-cylinder* and *piston*, the piston-rod of which is connected to the brake-rods in such a manner that when compressed air is admitted to the cylinder, and the piston moves outward, the brake-shoes are pressed against the tread of the wheels.
6. An *operating valve* placed at either end of the car, by means of which compressed air can be admitted from the reservoir into the brake-cylinder and exhausted from the brake-cylinder to the atmosphere.
7. A *system of piping* connecting the above-mentioned parts, and, when trailers are used, including flexible hose and couplings and cut-out cocks.
8. A *safety-valve* connected to the reservoir to prevent too great an accumulation of air should the governor fail to operate.
9. A *chime whistle* connected to the air-supply, to be used as a warning of approach.

The general arrangement, names, and relative location of all parts, are shown diagrammatically in Fig. 73.

Operating the Straight Air-Brake. The operating valve has notches placed upon it which mark the position of the handle for the various positions of the valve. This fact enables one to operate the brake with certainty the first time, but smooth and accurate stops can be made only after a little practice. Beginning from the right and going to the left, the different positions of the valve handle are as follows: *Emergency position, service position, lap position,* and

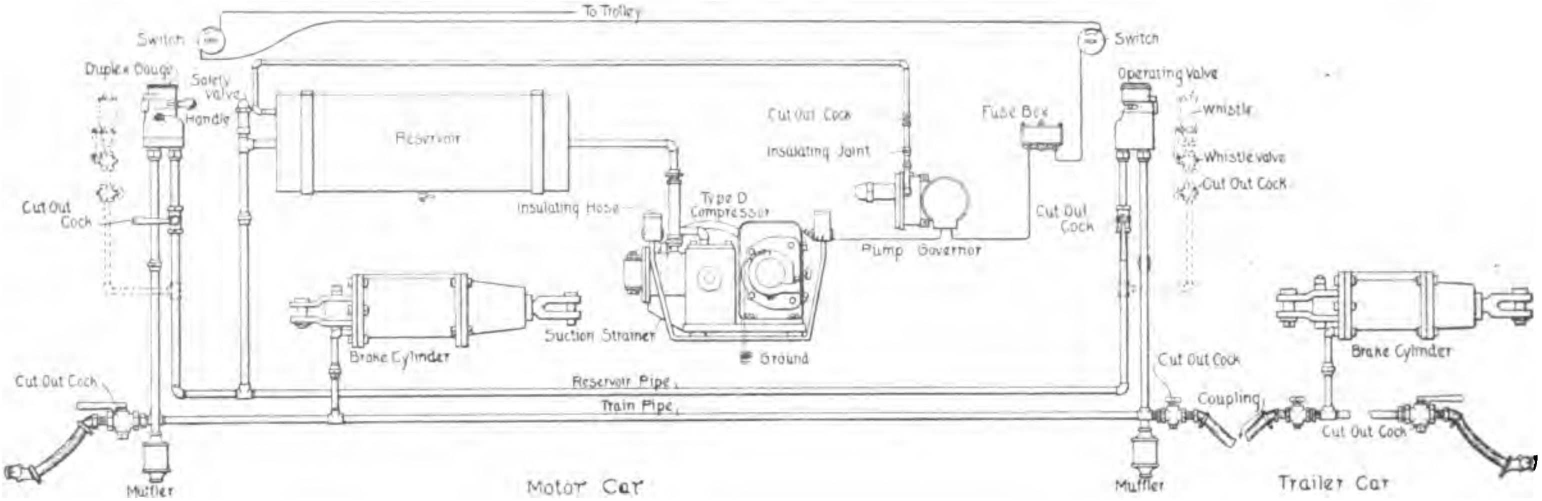


Fig. 73. Diagram of Westinghouse Straight Air-Brake System.

release position (see Fig. 83). When the handle is in the lap position, as indicated by the deep notch, the main ports in the valve are closed, and compressed air cannot enter the brake-cylinder from the reservoir, and any compressed air which may be in the brake-cylinder cannot exhaust into the atmosphere. If the handle is now moved from this position to the extreme left, it will then occupy the release position. In this position, any air which may have been in the brake-cylinder will be exhausted into the atmosphere, and the brake will be released. This is the position the handle should occupy while running on a level track. If the handle is moved from the release position to the service position, air will flow very slowly from the reservoir into the brake-cylinder, and service application results. If, however, the handle is moved from the release position to the extreme right (the emergency position), a large amount of air rushes from the reservoir into the brake-cylinder, and an emergency application is obtained. If the car is coasting down a grade, and the handle is moved to the service position for an instant and immediately returned to lap position, a small amount of air is admitted to the brake-cylinder and retained, thus holding the brakes applied. With a little experience, the proper amount of air can be admitted to the brake-cylinder in order that a constant speed may be maintained. If too much air is admitted into the brake-cylinder, a small portion can be exhausted by throwing the handle to release position for an instant, then back to lap position.

The quickest stop possible is made by throwing the handle at once to the emergency position, giving to the wheels the greatest possible braking pressure. The higher the speed, the greater the pressure that can be applied without danger of sliding the wheels. Thus it is seen that the quickest stop can be made by applying at once full braking pressure (depending on the speed), and gradually releasing as the speed decreases. This method insures a smooth stop, as the rapid reduction of speed at the end of the stop, which throws passengers forward, is avoided. In making a service stop, about twenty-five or thirty pounds of air-pressure should be quickly admitted to the brake-cylinder, and gradually reduced as the speed decreases, retaining about ten pounds in the cylinder until the car stops. A little experience is necessary in order to know just what pressures to use to be able to stop in a given distance. A succession of applications and release in stopping a car imparts a very disagreeable motion to the car, and is very wasteful of compressed air. In making emergency applications, the handle is thrown to the emergency position, and brake-cylinder pressure of, say, 60 pounds is obtained almost instantly. Sand should then be applied, and the handle be brought at once to the lap position. The brake-cylinder pressure should then be released little by little as the speed drops.

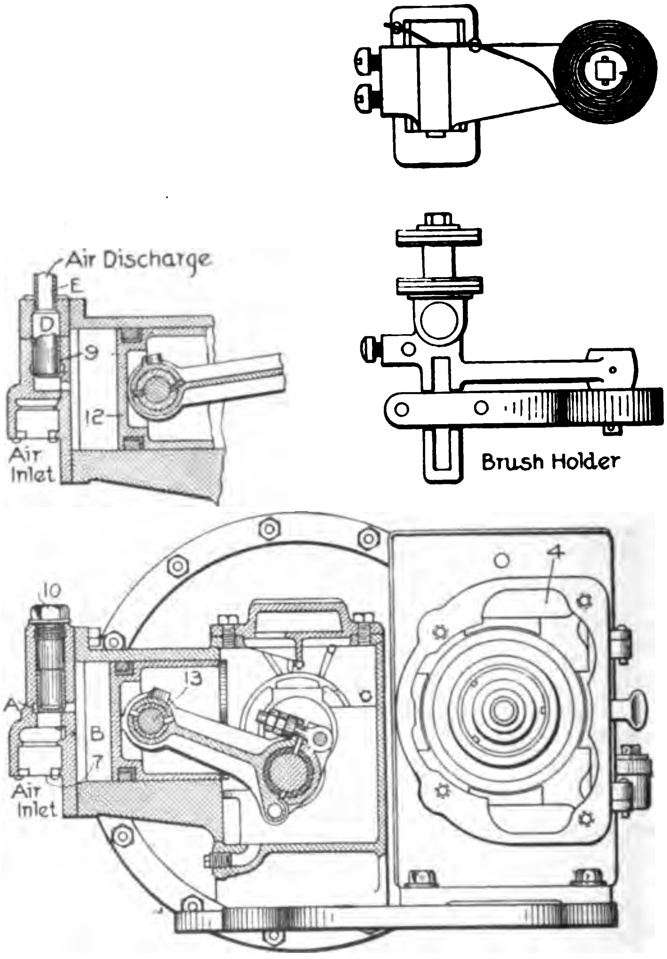
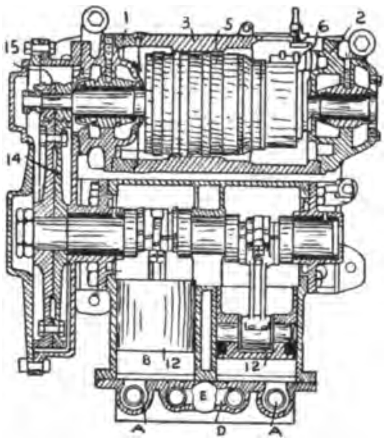


Fig. 74. Motor-Driven Air-Compressor.

When the signal is received to go ahead, the handle should be placed in release position before turning on the power. When descending a grade, the inexperienced man usually makes the mistake of applying the brake too hard at the start. It should be borne in mind that the car will not at once take the speed desired, and that some time is required for conditions to become constant. An easy application should first be made, and the handle held on *lap* until the car has sufficient time to feel the effect of the brake. If the speed of the car is still too high, let in a little more air, and repeat the operation as often as is necessary until off the grade.

The following instructions are given by the Westinghouse Company to motormen:



> "When leaving the car, always set up the hand-brake, as some one might tamper with the cut-out cocks. Before starting from the car-barn, be sure all cocks are properly set, and that there is a good supply of air in the reservoir. Insert the handle in its socket in the operating valve, and throw it around to emergency, then back to release, to see that it works freely. Try the air-brake both in *service* and in *emergency*, to make sure that it has not been left improperly connected, etc. After this trial, and as long as proper pressure is maintained, the brake may be relied upon to perform its duty."

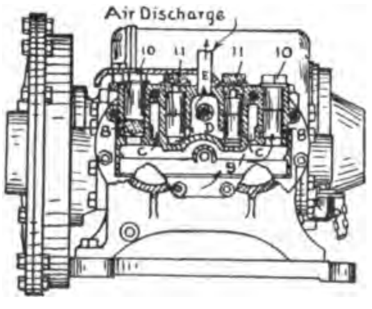


Fig. 75. Motor-Driven Air-Compressor.

Air-Compressor. The air-compressor may be either axle-driven or motor-driven. Since there are some objections raised against using the axle-driven compressor, and since the motor-driven compressor is more commonly used, it is deemed advisable to confine ourselves to the motor-driven compressor. Reference will be made to Figs. 74, 75, and 76. All metal parts, such as pistons, rods, frames, etc., will be referred to as 1, 2, 3, etc., while all cavities and chambers will be called *A*, *B*, *C*, etc.

The motor is of the series type, having an opening at the commutator end which permits of ready access to the commutator. This opening is provided with a tight-fitting door which excludes all dirt, dust, and moisture. In the ends of the frame are fitted heads (1) and (2), which provide bearings for the ends of the armature. Each bearing is provided with two oil-rings which secure proper lubrication of the shaft. Oil-holes are provided for filling the oil-wells, and the location is such that there is no danger of flooding the interior of the motor with oil. A passageway at the pinion end conducts any excess of gear-lubricating oil to the bottom of the gear case, thus assisting in preventing any flooding of the motor. Two of the poles of the motor are a part of the frame (3), and two are made up of soft laminated iron (4) bolted to the frame. The armature (5) is made up of soft-steel punchings which have accurately spaced slots in which are imbedded coils of uniform size. The brush-holders (6) are made of brass and are bolted to a cast-iron yoke with proper insulation. The brushes are carbon, and are held against the armature by coiled springs.

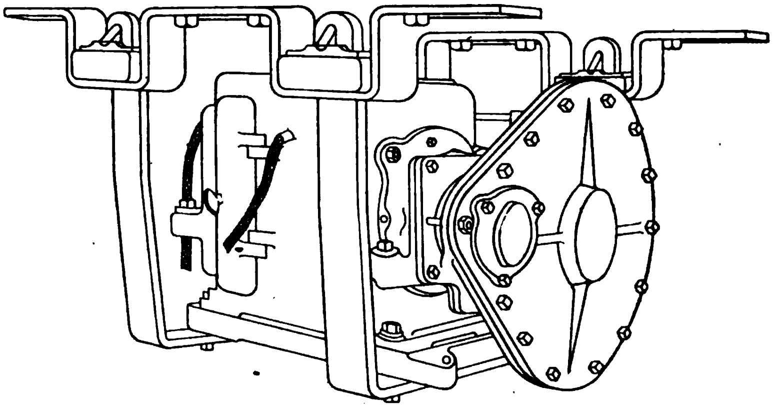


Fig. 76. Air-Compressor Suspended in Cradle under Car.

The action of the compressor in compressing air is as follows: Air is drawn through the suction screen (7), lifts the check-valves (8), and passes through the ports *A* into the cylinders *B*. On the return stroke, the compressed air is forced out through the ports *C*, lifting the discharge valves (9), then passing into the chamber *D*, and finally into the discharge pipe *E*. The suction and discharge valves are made of steel, and are accessible by removing the caps (10) and (11), respectively. These valves do not have any coiled springs to seat them, but close by gravity.

The pistons (12) are accurately fitted with rings, and are made long so as to reduce the amount of wear. When repairing the pump, the rings should always be kept with the piston to which they belong. The wrist-pin (13) is made of steel, and works on a bronze bushing in the connecting rod. The crank end of the connecting rod is lined with babbitt which works on the crank, and has suitable means for adjustment. The center line of the cylinders is placed above that of the crank-shaft, in order that the angularity of the connecting rod may be reduced during the compression stroke. This reduces the vertical component of the thrust on the pistons, and thereby reduces the amount of wear on the cylinders. It should be remembered, however, that the pump should always run with the compression part of the stroke on the upper half of the revolution. The crank-shaft is made of forged steel, and has two bronze bearings, one at either end, and a babbitt bearing in the middle. The crank-shaft bearings, wrist-pins, and crank-pins are lubricated by the splash system, from a bath of oil in the crank-case. The gear wheels (14) and (15) are of the *herringbone* type, and are lubricated from a bath of oil in the dust-proof gear-case.

An air-compressor heats very rapidly when in operation, if no means are provided to conduct the heat away. For this reason, compressors which are designed for continuous service are always water-jacketed. Since compressors for electric-car service are used intermittently, they have time to cool, and a water-jacket is unnecessary. Experience has shown that such a compressor as just described, when compressing air at 100 pounds per square inch, should not run longer than 15 minutes at a time, and should then be permitted to cool at least fifteen minutes. This compressor is suspended under the car, in the position shown in Fig. 76, when in service. The method of suspension permits of its being readily removed for repairing.

Pump-Governor. The location of the governor is shown in Fig. 73. Its purpose is to start and stop the compressor in order to maintain a predetermined pressure, by alternately making and breaking the circuit leading to the motor. A front view of the governor is shown in Fig. 77, and sections are shown in Figs. 78 and 79. The chamber *A* is in communication with the reservoir. The other side of the diaphragm (1) which forms one wall of the chamber *A* is open to the atmosphere. The diaphragm (1), therefore, is subjected to reservoir pressure on one side and atmospheric pressure and the regulating spring (2) on the other. The slide-valve (3) is connected to the diaphragm (1) in such a manner that any movement of the latter operates the former. When the maximum pressure is attained, the regulating spring (2) is so adjusted that the diaphragm (1) is pressed downward. This moves the slide-valve (3) and uncovers the port *B*, which is in communication with the chamber *C*. The air-pressure now in the chamber *C* forces the piston (4) upward, thereby opening the switch in the motor circuit, and the motor stops. When the air-

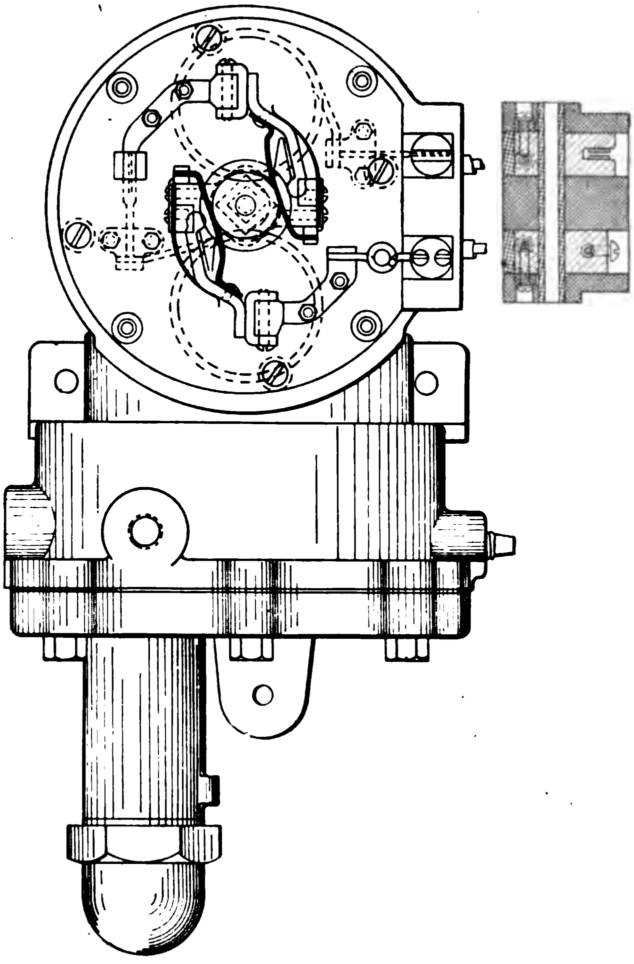


Fig. 77. Pump-Governor for Air-Compressor, Front View.

pressure in the reservoir drops slightly, and consequently the pressure above the diaphragm (1) is reduced, the regulating spring (2) forces the diaphragm upward, which also moves the slide-valve (3) and connects the port *B* with the exhaust port *D*. Air from the chamber *C* is now exhausted into the atmosphere; the piston (4) moves downward and closes the switch in the motor circuit; and the pump starts. This action continues, and maintains the required pressure in the reservoir.

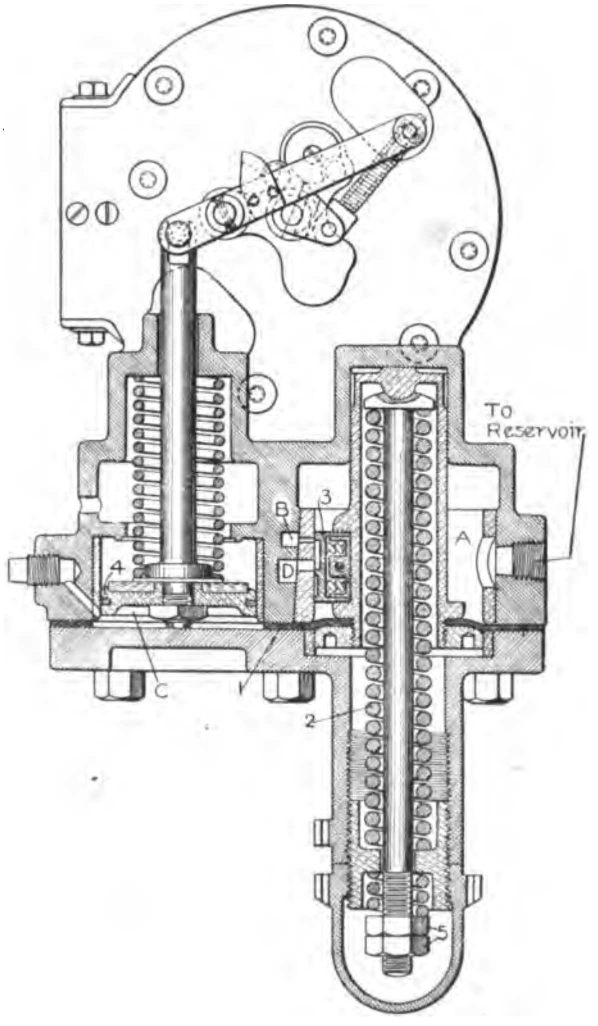


Fig. 78. Section through Pump-Governor for Air-Compressor.

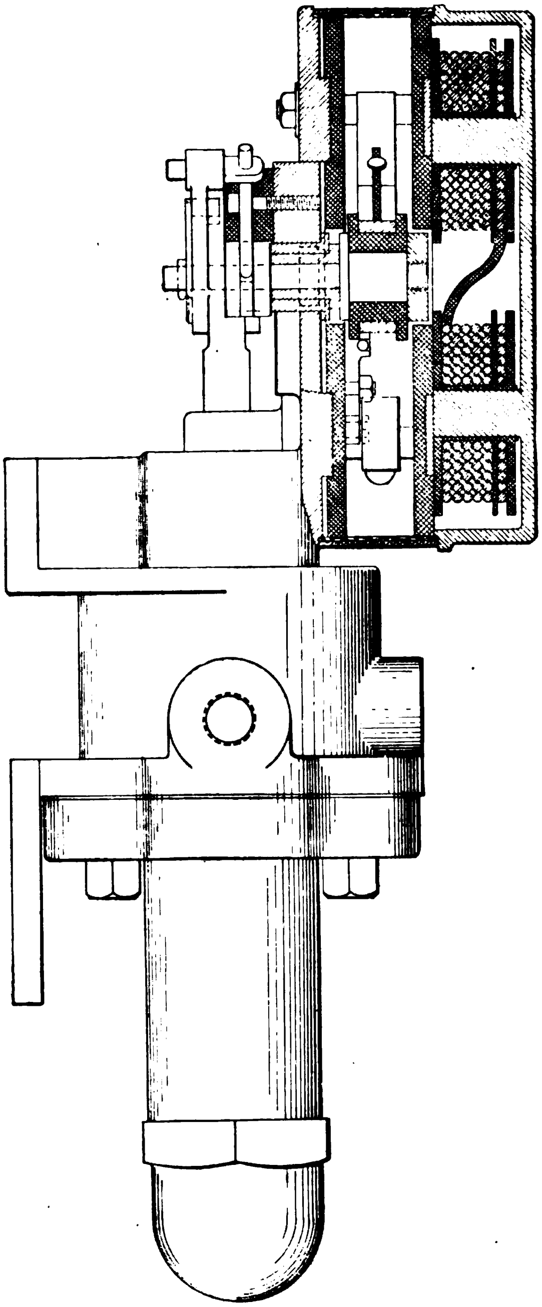


Fig. 79. Pump-Governor for Air-Compressor, Side View.

The mechanism on the upper part of the governor acts so as to cause the switch to open and close very rapidly, and thus avoids undue arcing. The pressure at which the governor cuts out the motor is controlled by adjusting the regulating spring (2) by means of the nuts (5). The governor may be located either under the car or in one end of the car.

The electric apparatus above described is for direct current. Alternating-current motors and governors are being used to some extent, but have not yet come into very general use.

Reservoir. The reservoir should have a sufficient capacity to supply air for three or four applications without reducing the pressure more than 15 pounds. It is conveniently located under the car, and its dimensions depend upon the size of the brake-cylinder used. It serves to collect moisture and oil, and prevents them from being carried further into the system. It should be drained frequently, as its capacity for stored air will be reduced proportionally to the volume of water it contains.

Brake-Cylinder. The brake-cylinder shown in Fig. 80 is of the hollow-rod type. The piston is connected to the brake-rigging in such a way that it moves only when the power-brake is used. When the hand-brake is used, no movement of the piston occurs. The piston rod (1) is made hollow to receive the push rod. A leather packing-ring (2) is provided which prevents air from leaking around the piston. The leather packing-ring is held against the walls of the cylinder by means of the round spring expander (3). The cylinder-head (4) may be either plain or as shown. That shown is constructed to

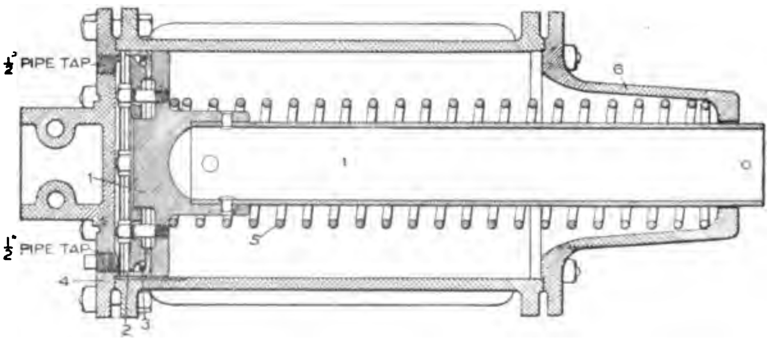


Fig. 80. Brake-Cylinder of Hollow-Rod Type.

receive an automatic slack-adjuster (see page 79), which is sometimes used with the automatic system.

When an application is made, air enters behind the piston and forces it outward, compressing the release spring (5). When the air is exhausted from the cylinder, the release spring (5) pushes the piston back to its normal position. Cylinder head (6) is constructed so as to provide a place for the coil spring when the piston is forced outward.

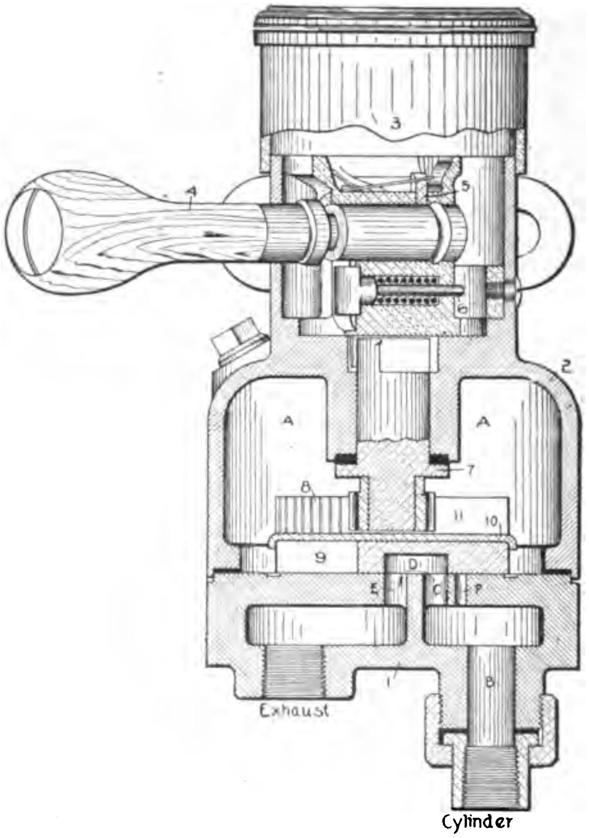
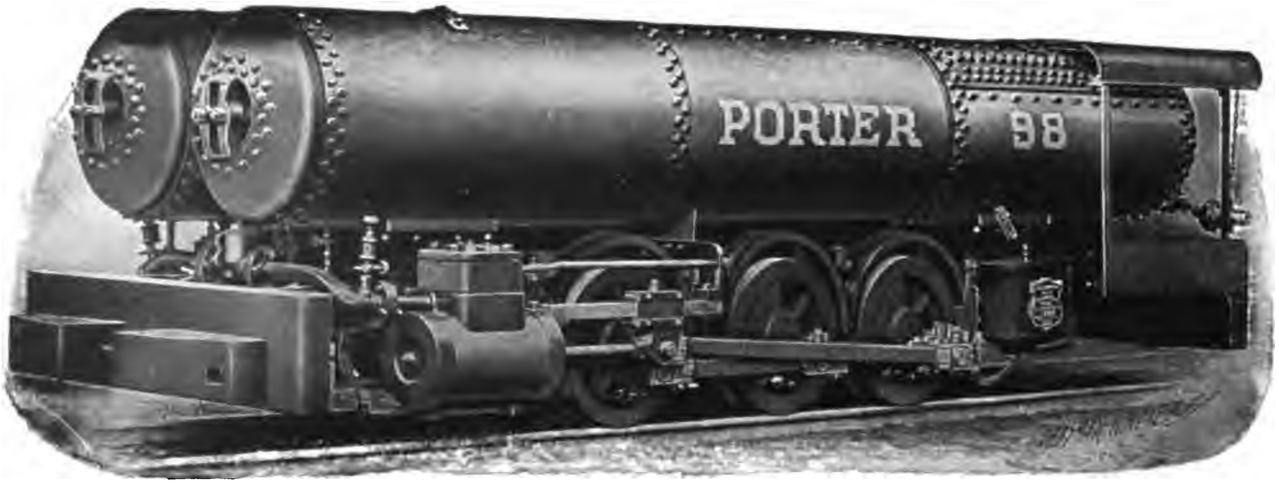


Fig. 81. Operating Valve of Westinghouse Straight Air-Brake, View Showing Slide-Valve.

The size of the cylinder depends on the design of the brake-rigging and on the weight of the car. The sizes commonly used are 8, 10, and 12 inches in diameter.

Operating Valve. The purpose and operation of the operating



FRONT VIEW PORTER COMPRESSED AIR LOCOMOTIVE.

valve has already been described (see page 91). The four positions of the valve are: *Emergency, service, lap,* and *release.*

When in emergency position, full braking pressure is obtained almost instantaneously, and is used in avoiding collisions and making quick stops. In this position, direct communication is made between the reservoir and the brake-cylinder. The rail should always be sanded to avoid the possibility of slipping the wheel, which would result in making a poor stop and would probably cause a flat spot on the wheel.

In service position, air enters the brake-cylinder pipe through a small port in the operating valve, and applies the brake very slowly.

When in lap position, the ports in the operating valve are blocked, and air can flow neither to nor from the brake-cylinder. If the brake is applied, it will remain so until the valve is thrown to release position.

If the valve is placed in release position, the cylinder and exhaust ports are connected, and only atmospheric pressure will remain in the cylinder. If the brake has been applied, it will release when the valve is placed in this position.

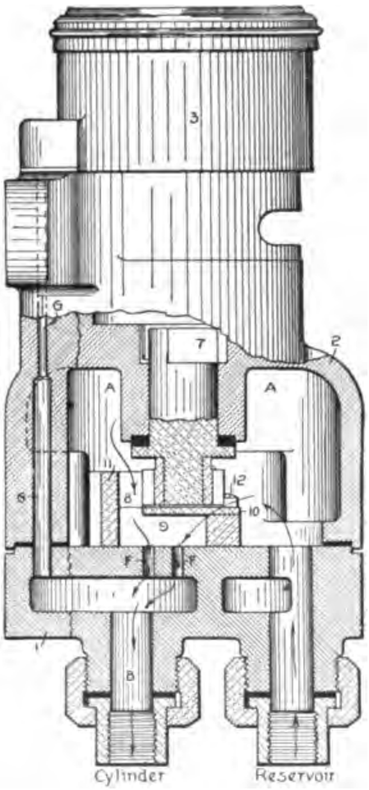


Fig. 82. Operating Valve of Westinghouse Straight Air-Brake, View Showing Reservoir Cavity.

In describing the operating valve, reference will be made to Figs. 81, 82, and 83. The valve is cast in two parts—the base (1) and the head and body (2). On the top of the head is a double gauge (3); the red hand indicates the reservoir pressure; and the black hand, the brake-cylinder pressure. Just below the gauge is a socket into which fits the operating handle (4) which is removable. In swinging from release position to emergency position, the handle turns through about 130 degrees. The handle can be inserted and withdrawn only when the valve is in lap position. When the handle is withdrawn, the latch (5) is thrown into position by a small spring, and the valve is permanently locked until the handle is again inserted. Just below the handle socket is a second one which contains a bolt (6) actuated by a spring. As the handle is turned, the head of the bolt (6) passes over notches which serve to indicate when the valve is in the proper position. Connected to the lower side of the socket is the stem (7) having a pinion fitted to its lower end, which actuates the rack (8). The rack (8) is connected to and operates the slide-valve (9). The spring plate (10) does not act as a stop for the slide-valve (9), but is used only to assist in getting the valve in the proper position when assembling the parts. The slide-valve (9) moves between suitable guides (11) and (12). The chamber A is always in communication with the reservoir, and a port leads to the gauge above, which indicates the pressure. In the figure, the valve is shown in release position; air passes from the cylinder through the pipe B, the port C, the cavity D, the port E, thence to the exhaust pipe. When the valve is in emergency position, the right-hand edge of the slide-valve (9) registers with the left-hand edge of the port C. Air then passes from the chamber A, through the ports C and F, through the pipe B, to the brake-cylinder. In this position, the port E is blocked. In lap position, the right-hand portion of the slide-valve (9) covers the ports C and F, and the port E is blocked. The port G connects the brake-cylinder pipe with the gauge above, which indicates the cylinder pressure.

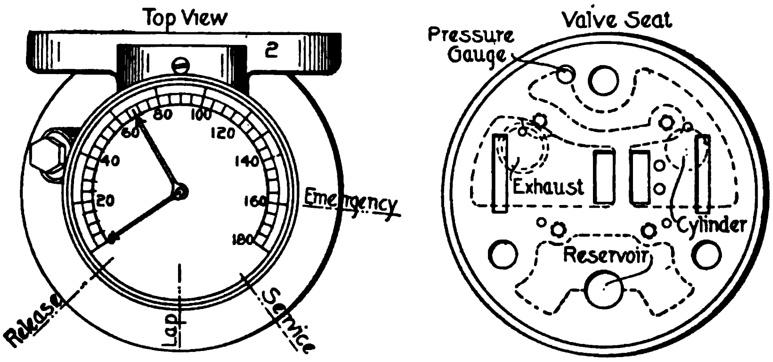


Fig. 83. Top View and Valve-Seat of Westinghouse Straight Air-Brake.

Another form of this operating valve is sometimes used which has no gauge at the top to indicate the cylinder and reservoir pressures. The operation of the valve is the same as in the case of the one just described.

The valve just described is sometimes used in a modified form as shown in Fig. 84. Here the operating handle and valve parts are separate, and the valve parts are bolted to the floor of the car. In operating this brake, the handle must be thrown in a way the reverse of that just described, but otherwise the operation of the valve is the same as previously given.

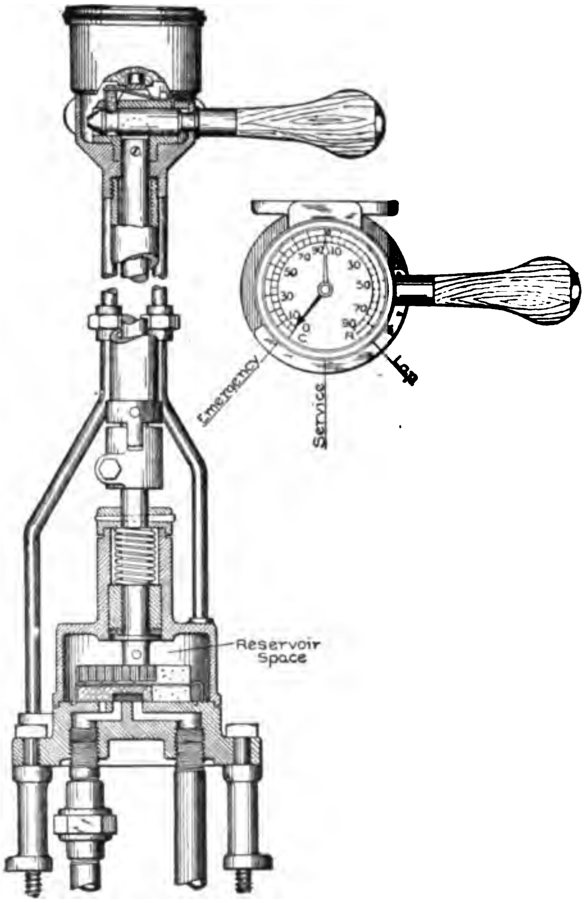


Fig. 84. Type of Operating Valve with Handle and Valve Parts Separate. Westinghouse Straight Air-Brake System.

Piping. Referring to Fig. 73, the sizes of the various pipes are as follows:

The train-pipe connecting the brake-cylinder with the operating valve should be a standard ½-inch pipe. If more than one trailer is used, a ¾-inch pipe should be used.

The reservoir pipe, connecting the reservoir with the operating valve is a ½-inch pipe. A ¾-inch pipe is better if it can be used conveniently.

The pump-governor and whistle connections are made with ⅜-inch pipes. Wherever possible, long bends in pipes should be used, rather than a standard elbow fitting.

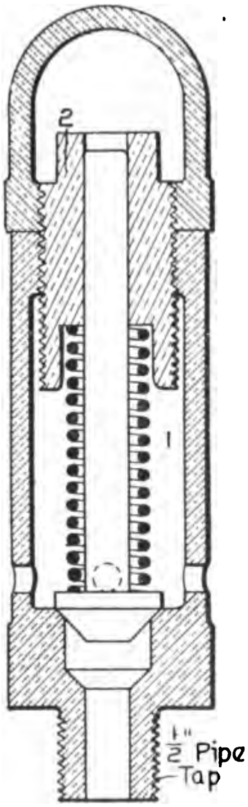


Fig. 85. Safety-Valve of Westinghouse Straight Air-Brake.

Safety-Valve. The safety-valve should be connected to the reservoir line leading to the controlling valve, at a point near the reservoir. Its operation may be understood by reference to Fig. 85. It can be set for any pressure by adjusting the regulating spring (1) by means of the nut (2).

In an axle-driven compressor equipment, a slight change in the piping is necessary from that above described. Since the compressor is mounted on the truck, and has some movement relative to the car frame which carries the reservoir, flexible hose connections are necessary, to make connections to the reservoir and also to the compressor regulator. A small reservoir is also used which receives air from the compressor. This small reservoir is connected to the main reservoir by a pipe containing a regulating valve. The air attains a pressure of about 35 pounds in the small reservoir before any air passes into the main reservoir. This 35 pounds' pressure in the small reservoir is attained while the car runs about 100 yards, and is available for applying the brakes. This always insures air for operating the brakes if the car previously runs a short distance. With this ex-

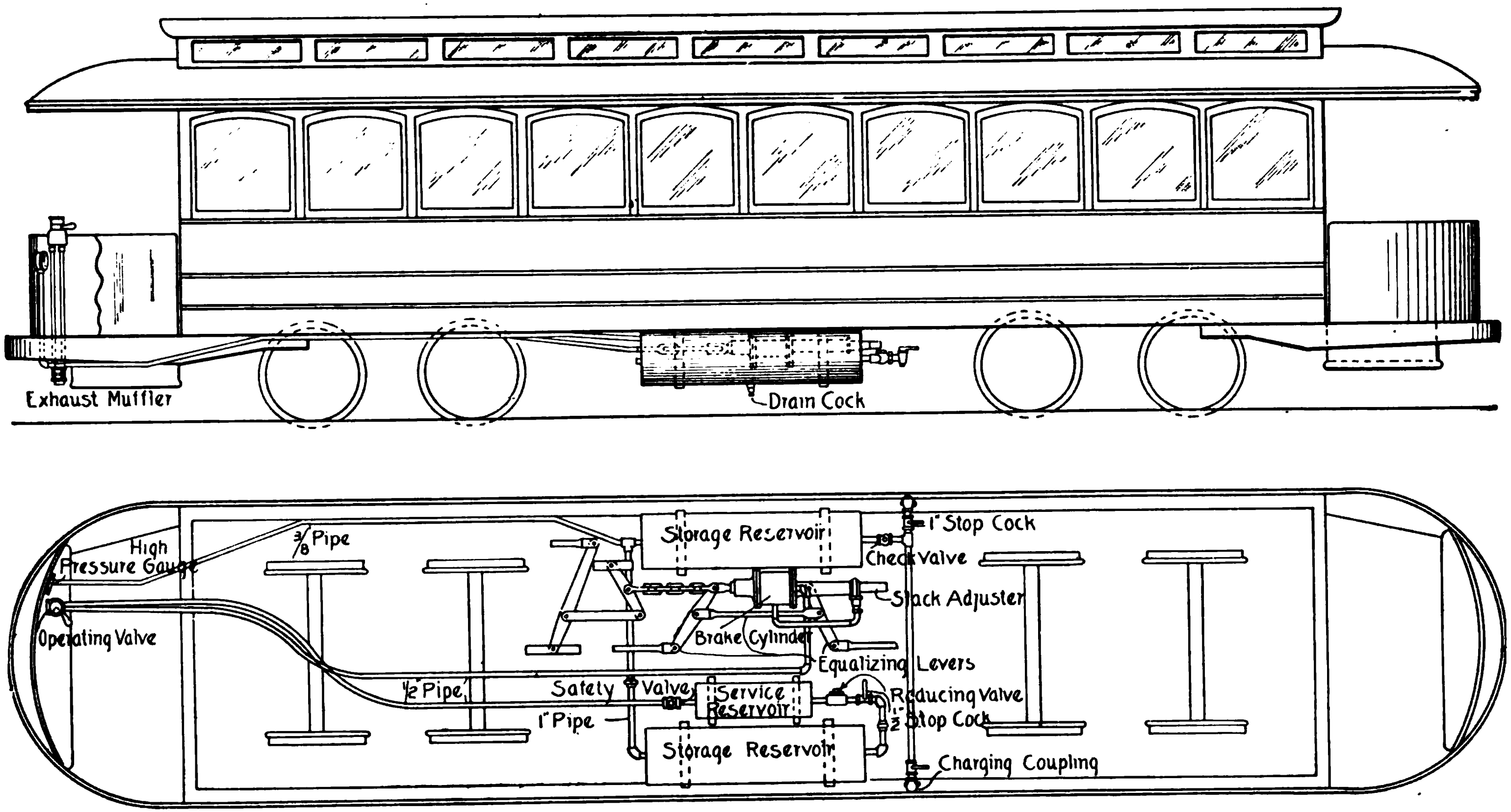


Fig. 86. General Scheme of Storage Air-Brake Equipment on a Car.

ception, the piping is the same, and no further description is necessary.

If a car is fitted with a storage air-brake equipment, no compressor is installed in the car. The compressed air which is used for braking is carried on the car in large reservoirs. The general scheme of a storage air-brake equipment is shown in Fig. 86. Two large reservoirs connected by a one-inch pipe carry air at high pressure. These reservoirs deliver air through a reducing valve to a service reservoir. The pressure in the service reservoir corresponds to that in the reservoir previously described. Other than these parts just mentioned, the straight air-brake and the storage air-brake systems are the same.

Westinghouse Automatic Friction-Brake. The general scheme of this equipment is shown in Fig. 87, which gives the names of the principal parts and their relative location. The principle of its operation is

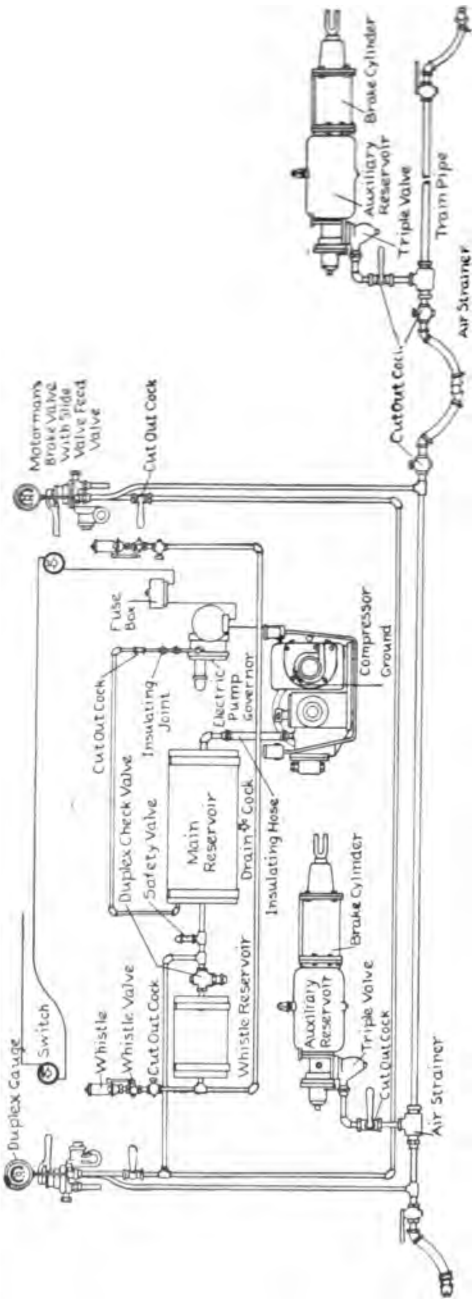


Fig. 87. Westinghouse Automatic Friction-Brake. Motor-car equipment shown at left; trailer-car equipment at right.

very different from that of the straight air-brake system. In the straight air-brake system, the brake-pipe is subjected to pressure only when an application is made. With the automatic system, air at 70 pounds' pressure per square inch is carried in the brake-pipe. The brake is applied by exhausting air from the brake-pipe, thus reducing its pressure; and it is released by restoring this pressure. It follows that any accident or operation which results in reducing the brake-pipe pressure will apply the brakes on all cars. This is not true, however, in case of the straight air-brake system. In the straight air-brake system, if any accident occurs to break or open the brake-pipe, the brake at once becomes inoperative. With the exception of compressed air being supplied by a motor-driven compressor, a governor controlling the operation of this compressor, and a change in the form of the brake-valve, the system is almost identical with the Westinghouse system already described for steam-operated roads. The descriptions of the operation of the automatic brake already given apply equally well to the automatic system for electric cars. The system is especially recommended for use on trains of more than two cars, where frequent stops are not required.

The standard automatic air-brake system as used on steam roads to-day cannot be successfully operated on electric trains for street service composed of one car, for the following reasons:

First. Applications of the brake are likely to follow in such rapid succession that sufficient time would not be given to properly recharge the auxiliary or braking reservoir on each car.

Second. A graduated release or gradual decreasing brake-cylinder pressure is absolutely necessary in electric-car work, in order to obtain a smooth stop. With the standard automatic equipment, release of the brake-cylinder pressure is complete, when once started.

Third. A prompt response of the brakes when re-applied after a release, is very essential. This is not always possible in the standard automatic equipment, since the auxiliary reservoir is very slow in charging.

To overcome these difficulties, there has been devised an automatic system for electric-car work, having quick-service, graduated-release, and quick-recharging features. This system is very important for a certain class of service, but will not be described.

Train Air-Signal. As the size of electric cars and the length of trains increase, a signal system becomes more and more a necessity. That used to-day on steam roads has been fully described in preceding pages. Since the air-signal system used on electric cars is the same as that used on steam roads, it is unnecessary to repeat the description.

Stopping a Car. The brake equipment of all electric cars is calculated with reference to the unloaded weight of the car, that is—the parts are so designed that there will be no danger of slipping the wheels when the car is unloaded. In stopping a car, the forces which act to retard its motion are:

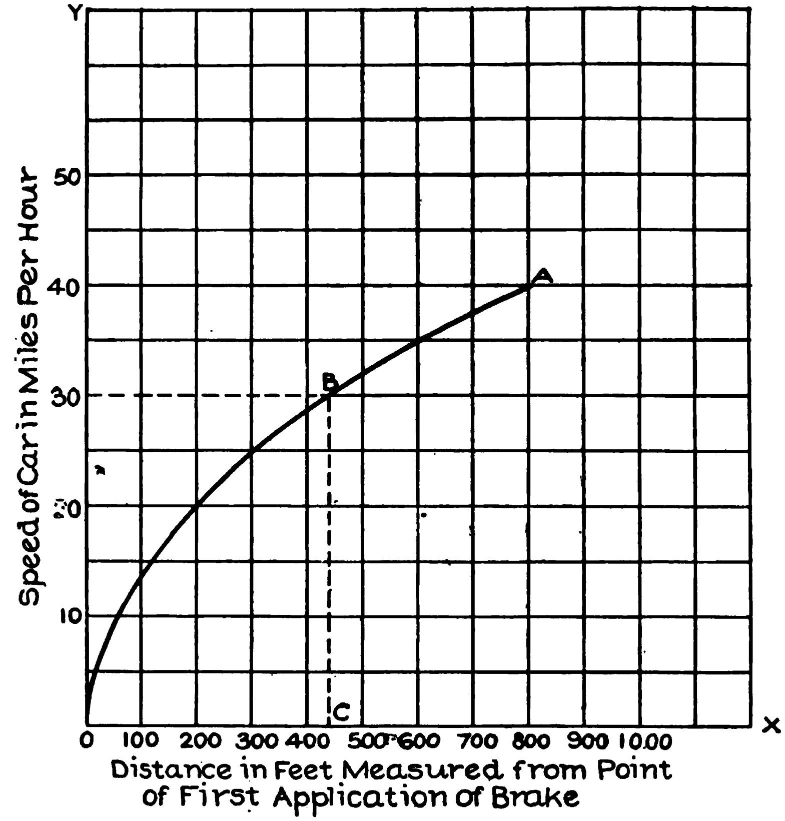


Fig. 88. Diagram Showing Relation between Speed of Car and Distance in which Stop can be Made after Application of Brake.

The resistance of the atmosphere;

The frictional resistance of the journals and track; and

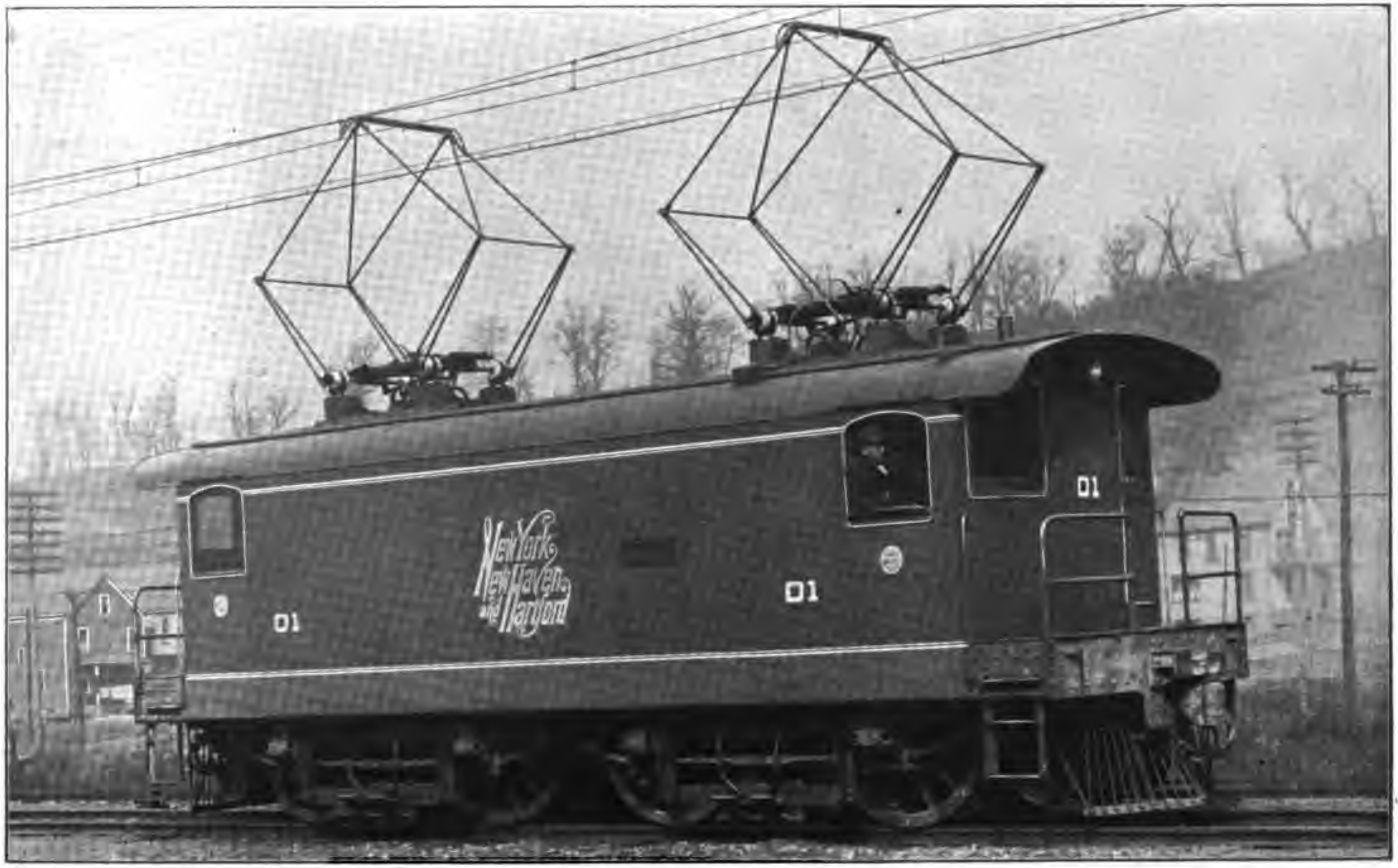
The resistance of the brake-shoes on the wheels.

When the brake is applied, the car pitches forward on the front truck, and the weight on the rear truck is thereby decreased. If proper allowances have not been made in proportioning the brake-levers, the rear wheels will probably slip on the track. If the wheels should slip, the distance required in which to bring the car to rest would probably be greater than that required had the wheels not slipped. In bringing a car to rest, the energy of translation of the entire car and the energy of rotation of all the wheels and motors must be absorbed by friction. To do this efficiently and safely in the shortest possible time, is the purpose of the modern brake systems.

The average person who rides on street and interurban cars knows nothing as to the distance in which these cars can be stopped. "In what distance can a modern double-truck electric car be stopped?" is a question which is frequently asked. In answer to this question, Fig. 88 has been prepared. A great many experiments have been made in stopping cars, with varying results. The chief factors which affect the results of such tests are the condition of the rail and the character of the material composing the brake-shoes. Fig. 88 shows graphically the relation between the distance required to stop a car and the speed (in miles per hour) at the instant the brake was applied. It represents the average result of a large number of experiments with a double-truck car fitted with brake equipment as described in the preceding pages. With perfect conditions, the curve $A\ B\ O$ would fall above that shown, while with very poor conditions, it would fall lower. The value of the diagram is made apparent by the following application:

Example. Find the distance in which a double-truck electric car may be stopped if power is shut off and the brake applied while running at a speed of 30 miles per hour.

Solution. Starting on the vertical line $O\ Y$ at 30 miles per hour, follow the horizontal line to the right until the curve $A\ B\ O$ is reached at the point B. From the point B, follow the vertical line downward until the horizontal line $O\ X$ is reached at the point C. This point C indicates the distance in feet in which the car may be stopped, which in this instance is 440 feet. In the same way, the stopping distances may be determined for cars running at any speeds.



ONE OF THE SINGLE-PHASE LOCOMOTIVES ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD CO.
Note the two pantograph bow trolleys for collecting the current.

THE SINGLE-PHASE ELECTRIC RAILWAY.

In no other line of electrical activity have developments during the last few years been so rapid as in that of electric railway work, and from all indications the limit has not yet been reached.

Until recent years all electric traction has been dependent upon direct current as a motive power. This is due principally to the fact that the series direct-current motor is admirably adapted for such work, and no alternating-current motor had been developed which could be substituted for it. One of the great advantages possessed by the direct-current series motor is its large starting torque, which may be several times greater than that required to propel a car at full speed. This type of motor is also essentially a variable speed machine, and lends itself very well to wide variations in speed control; consequently, for many years, in this country at least, all advance was made along direct-current lines.

The trolley voltage used at first was from 450 to 500 volts, this being supplied directly to the cars by means of a trolley wire, the rails being used for the return circuit. It is evident from the outset that the comparatively low voltage, necessitating as it did a correspondingly large current for a given amount of power, would place a definite limitation on the use of such a system for anything other than purely local distribution. To overcome this difficulty as far as possible, the trolley voltage was gradually raised to 600 or 650. This of course decreased the required current, thus increasing the scope of the system accordingly. The limit of increase of direct-current voltage on the trolley was reached at about this point, and the fact was recognized that some means must be devised for using a still higher voltage, since there are difficulties to increasing the trolley voltage beyond 600 or 700, due to flashing of the motors, which seems to increase directly with the voltage.

It may be mentioned in passing that one prominent electric traction expert has stated that a direct-current trolley voltage of 1500 can be used, but it remains to be proven whether or not he is correct.

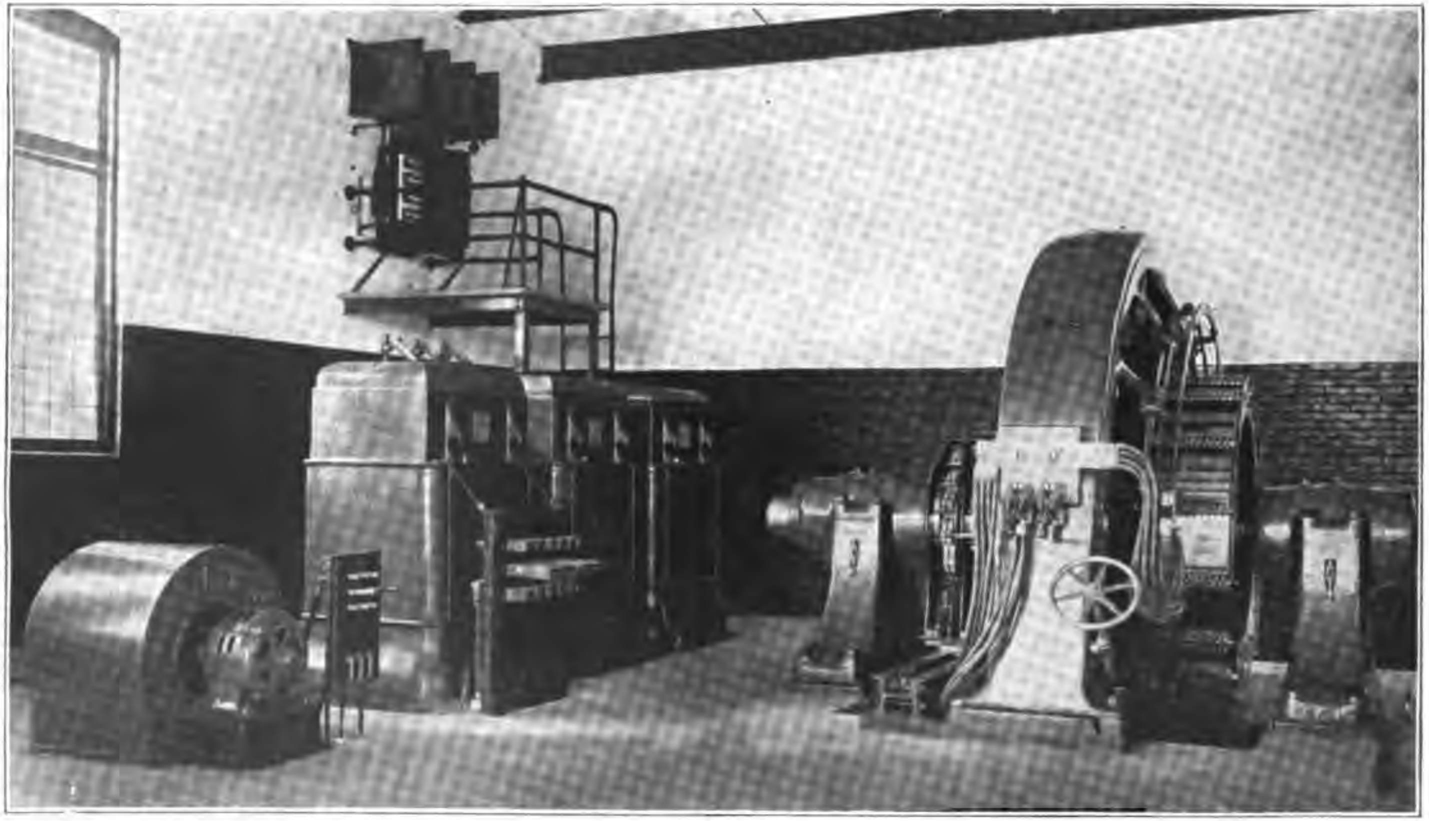
A very satisfactory solution of the problem for large city street railway systems and long interurban roads, consists in the use of a combination alternating-current direct-current system in which three-phase high tension alternating current is generated and distributed on high tension lines to substations along the road. It is here stepped down by means of transformers, and then changed to direct current by rotary converters, and supplied to the trolley wire as direct current at the usual voltage of say 600. This system has many advantages, as there is but small loss in the high-tension lines, and these lines can be made comparatively small, thus effecting a considerable saving in investment for copper.

The above mentioned system of distribution is very generally used, and has been found quite satisfactory. The substations can be located at frequent intervals, and the distance that the 600-volt current must be conducted to supply the cars is not great. By this means current can be distributed over wide areas with a small loss, where it would be impossible to use the straight direct-current system of distribution.

While, as stated, this furnishes a fairly satisfactory solution of the problem, it is far from perfect, as it necessitates the intervention of the rotary converter substation, in which the investment must be large; and moreover the cost of operation is high, as such a station requires skilled attendance on account of the somewhat intricate nature of the rotary converter. The ideal system, therefore, is one which does away altogether with the use of direct current, the power being generated, distributed, and utilized by the motors, as alternating current.

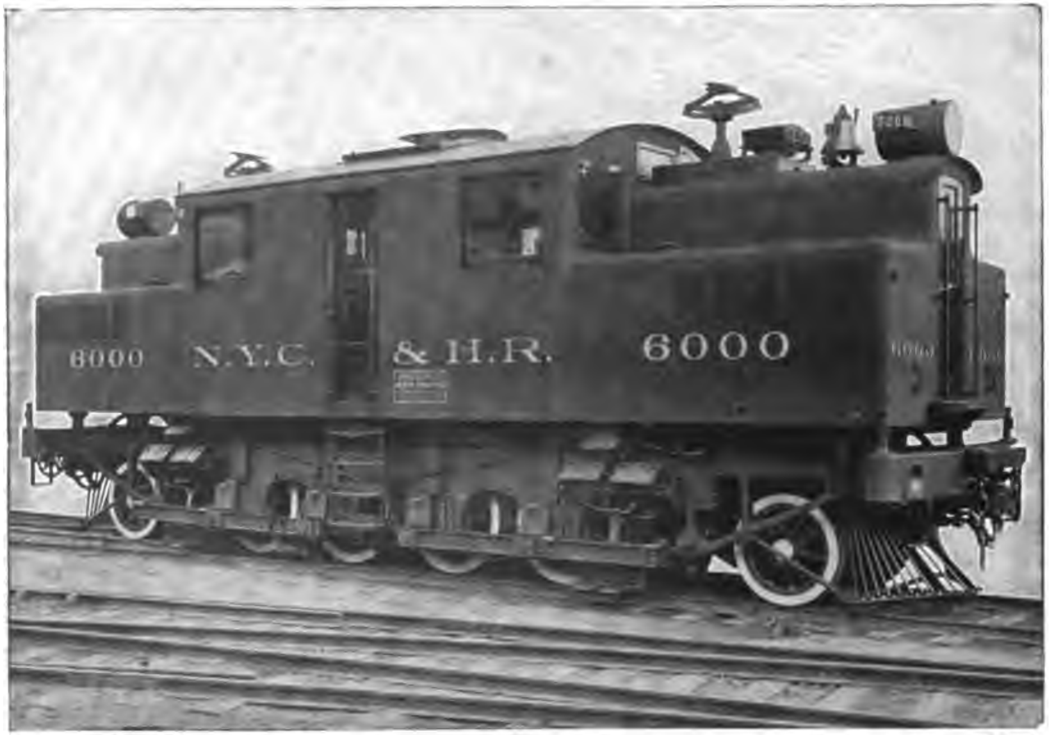
Three-phase induction motors have been used quite extensively and with considerable success in Europe for many years past. The three-phase motor, however, is not entirely adapted for railway work, since it possesses the characteristics of the shunt rather than of the series motor, being a constant speed, not a variable speed machine. Moreover, two trolley wires are necessary instead of one, and still another disadvantage consists in the low power-factor of the three-phase induction motor at starting.

The recent application of the single-phase alternating current to railway work has opened up a new field, which bids fair to supplant all other forms of distribution to a great extent at least, and



INTERIOR OF SUB-STATION SHOWING ROTARY CONVERTER AND TRANSFORMERS.

The three-phase current is delivered to the transformers where it is stepped down to the voltage required for the rotary converter. In this machine it is transformed to direct current and delivered to the trolley wire.



95 TON ELECTRIC LOCOMOTIVE FOR NEW YORK CENTRAL RAILROAD.

General Electric Company.

it is impossible to predict at the present time just what its limitations may or may not prove to be. This has been made possible by the development of a *practical commercial* single-phase motor, which permits of the use of alternating current on the trolley wire with all its advantages, and yet sacrifices few, if any, of the advantages of the direct-current series motor on the car.

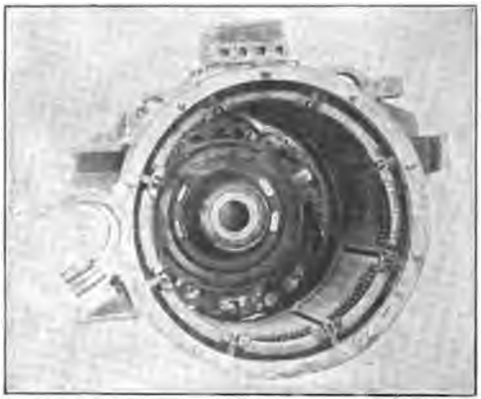
This motor, which is the latest and most important development in the electric railway field, is of the series commutator type, and does not differ in principle from its direct-current contemporary. It is called the *commutator type single-phase* motor, and is the one type of alternating-current motor which has the same desirable characteristics for railway work as the direct-current series motor.

Compensating Alternating-Current Railway Motor.

At first thought it may seem strange that a motor built fundamentally on the same lines as a direct-current machine would operate on an alternating current, as it might appear that the motor would tend to turn first in one direction and then in the opposite direction with no resultant motion. This, however, is not the case, because the direction of rotation of a motor depends upon the relative direction of its field and armature currents. If now the field were maintained in a constant direction and the armature supplied with alternating current, then the tendency would be to rotate first in one direction and then in the other, it is true, but as a matter of fact the alternating current is supplied to the field in series with the armature, so that when the direction of current in the armature changes it also reverses in the field. The result is that the relative direction of current in the field and armature is constant and the motor has, therefore, a tendency to turn continuously in one direction as long as the alternating-current power is supplied.

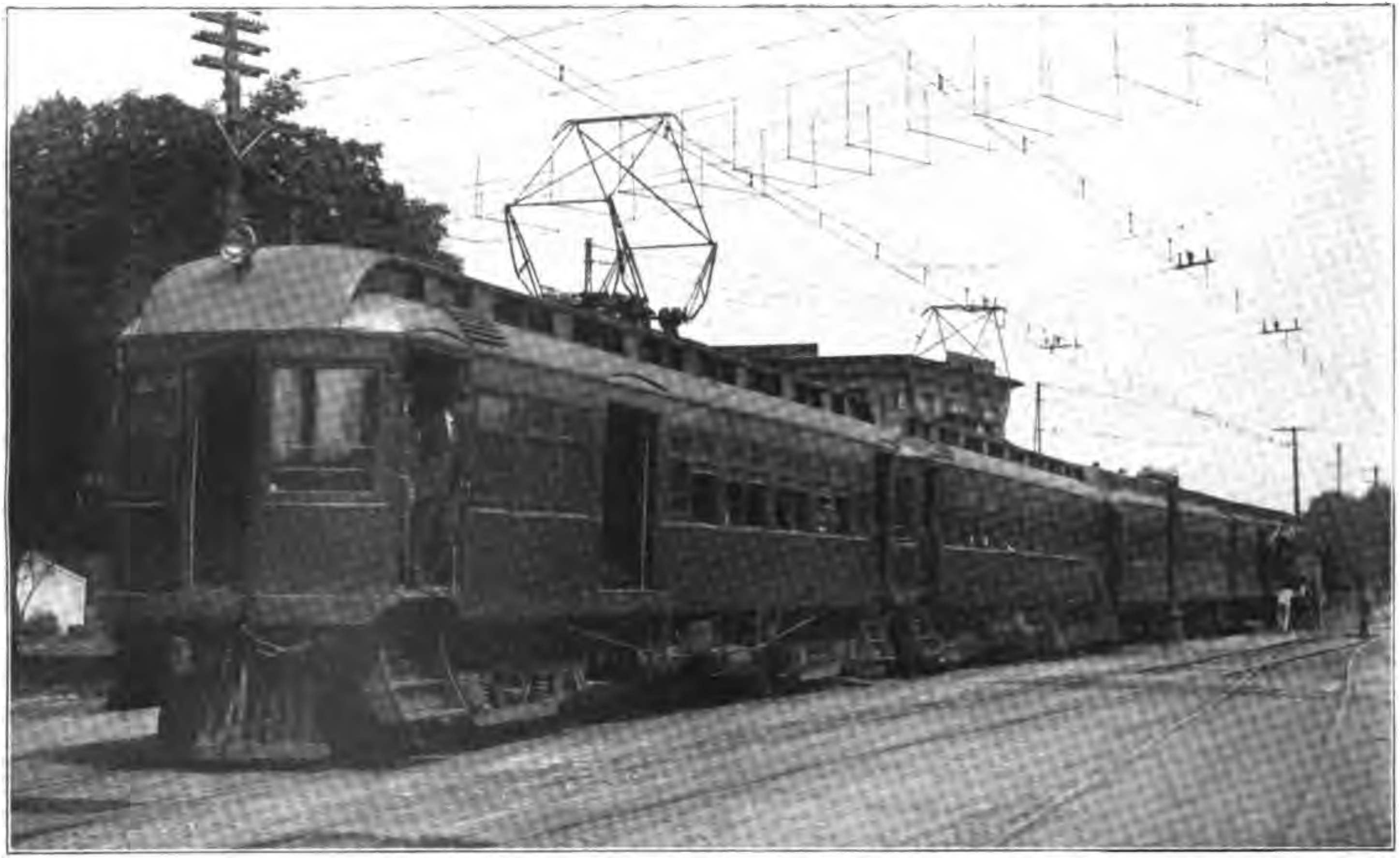
This being true, the question may arise as to why the single-phase motor was not brought to the front for railway work long ago. The answer is that there were certain inherent difficulties to be overcome, and the development of the single-phase motor has been simply the removal of these difficulties, rather than the design of an entirely new type of machine.

The most serious obstacle to overcome is the sparking at the commutator, due to the fact that when the terminals of a coil are bridged by a brush, the coil acts like the short circuited secondary of a transformer of which the field winding constitutes the primary. Also there is an iron loss due to the alternating magnetic flux through the magnetic circuit; while another objectionable feature is the counter E.M.F. induced in the field coils.



Alternating-Current Railway Motor Field.

In order that it may overcome these difficulties, to some extent, at least, the single-phase motor presents certain modifications from the direct-current type, in that it has more field poles, and the entire magnetic circuit of field frame, cores, and pole pieces, is carefully laminated. The number of commutator segments is also increased, thus reducing the number of armature turns per coil, and there are special features introduced to prevent sparking, such as compensating windings which neutralize the effect of armature dis-



FOUR-CAR TRAIN OF TWO MOTOR CARS AND TWO TRAILERS ON THE ROCHESTER DIVISION OF THE ERIE RAILROAD
Each Motor Car Has Four 100-H. P. Single-Phase Motors.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.

tortion; the use of narrow brushes; a type of armature winding which gives a low reactance per coil; the use of high resistance leads between the armature coils and commutator segments, etc.

The single-phase motor is then a refined and highly perfected type of direct-current motor, and this explains the fact that it will operate on either alternating- or direct-current circuits. In fact some claim that it will operate even more efficiently on direct current than the regulation direct-current motor itself.

Single-Phase Armature, Unmounted.

The field for which the single-phase motor seems particularly adapted is that of heavy service and interurban work, where it has many distinct advantages, among which may be mentioned the following:

The alternating current on the trolley allows the use of a high voltage and correspondingly smaller current, which reduces the line loss and permits of the use of smaller wire, which of course means a saving in the investment for copper. Moreover, the difficulty of collecting a large current from the trolley wire is overcome. Rotary converter substations are eliminated, being replaced by simple and cheap transformer substations, which require no attendance. The capacity can be easily increased by merely increasing the number of these transformer substations.

The efficiency of speed control is a point particularly worthy of mention. In direct-current speed control, the series-parallel method is used almost exclusively. This consists of putting the motors in series for low speed and in parallel for high speed. This permits of two, and only two, economical running points; the one at full speed, and the other at approximately half speed. All intermediate points must be obtained by the insertion of dead resistance in which the voltage is simply wasted as heat, thus causing a large loss particularly at starting.

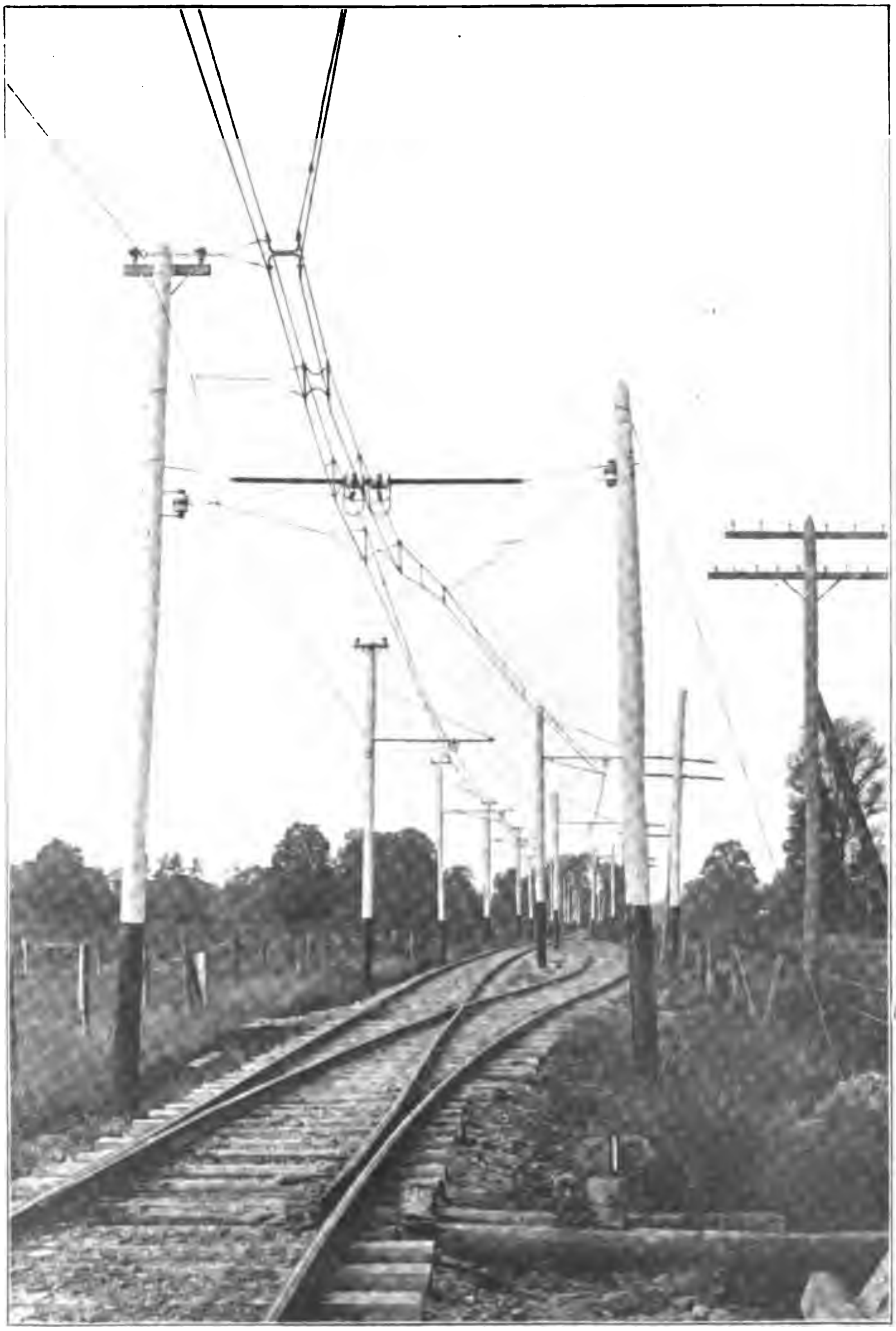
With the single-phase motor the current is supplied to the car with a voltage of say 3300. It is then stepped down by means of transformers on the car to the voltage of the motors, which may be 200 or 250 volts. The speed is, of course, dependent upon the voltage applied to the motors, and this voltage is cut down from the maximum, to obtain various gradations, by means of an induction controller, or by taps from an auto-transformer. Thus the motor takes from the trolley only slightly more power than is actually required to operate it at any given speed, instead of taking full voltage from the line and absorbing part of it in dead resistance.

The effect of electrolysis upon neighboring water pipes paralleling an electric road, which is the cause of so much trouble with direct current, is entirely eliminated, as electrolysis evidently will not take place with alternating current.

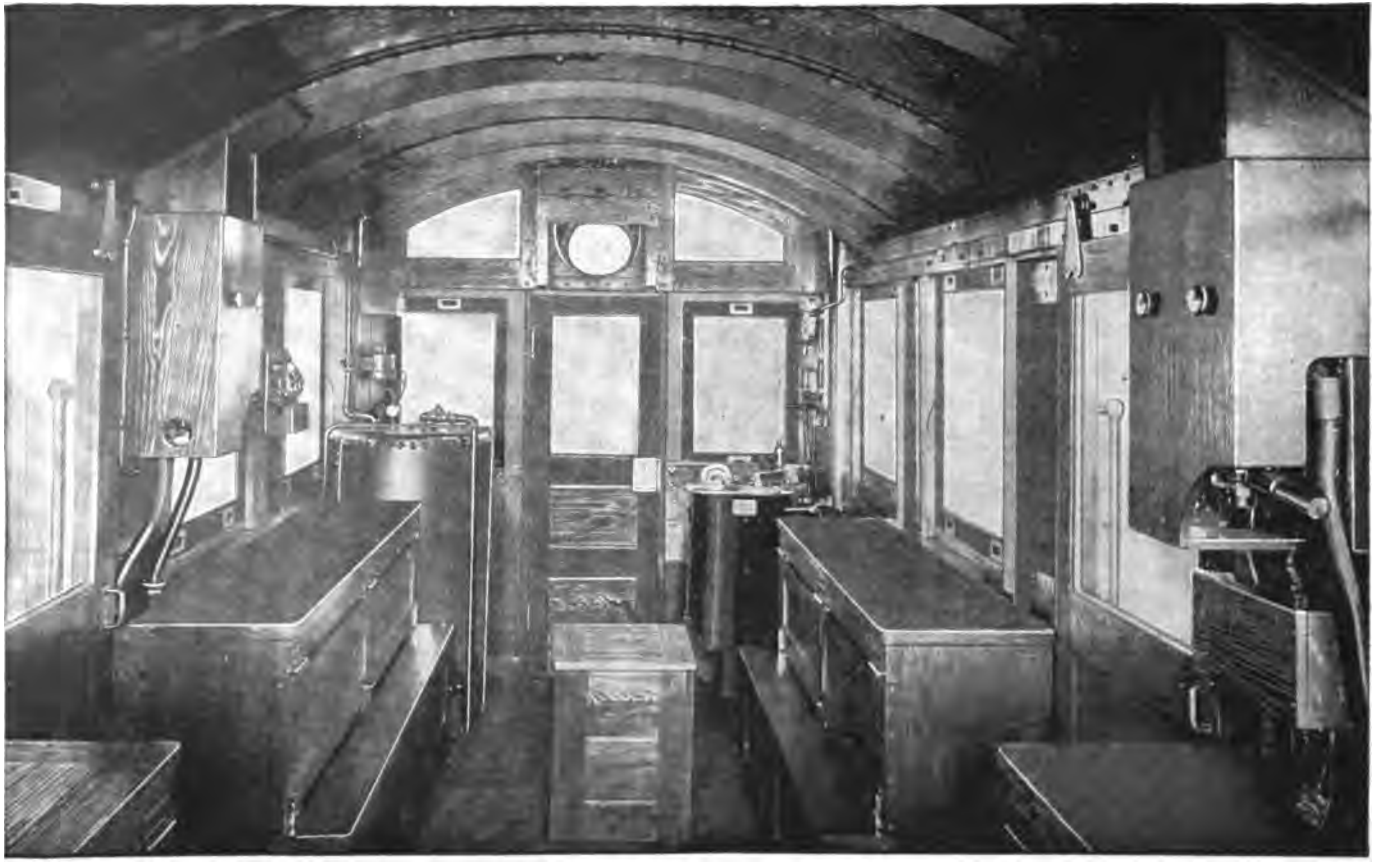
Auto Transformer.

In connection with this system a sliding contact device or bow trolley has in many cases been substituted with considerable success for the ordinary current collecting device, or trolley wheel, one advantage of this being that the car can be run in either direction without reversing the contact device. Another very satisfactory form of trolley is of the pantograph type with sliding shoe, shown on the New York, New Haven and Hartford locomotive.

A new form of trolley suspension known as the catenary has been developed to meet the demand for more substantial construction necessitated by the high trolley voltage. This consists of a stranded galvanized steel messenger or supporting cable, from which the trolley wire is suspended at intervals of about 10 feet, thus keeping it at a uniform distance above the track.



SINGLE-CATENARY LINE CONSTRUCTION ON THE WARREN AND JAMESTOWN SINGLE-PHASE ROAD
The Sleeve Type Insulators Shown Here Have Been Superseded by the Skirt Type.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.



INTERIOR OF 160-TON B. AND O. ELECTRIC LOCOMOTIVE.
General Electric Company.

The multiple-unit system of control can be used in connection with single-phase motors, this being the scheme which has been in use for a long time on elevated and other roads using direct current, whereby several cars can be operated in a train from a single point, each car being equipped with its individual motor and controlling apparatus. The entire system is then controlled as one unit by a single motorman stationed usually in the front of the first car. This method of control has become of such tremendous importance that any system to which it cannot be applied would be seriously handicapped. Cars equipped with single-phase motors can be operated on either direct-current or alternating-current lines, with high or low tension, with trolley or third rail.

Master Controller Used in Connection with the Multiple-Unit System as Applied to Single-Phase Work.

It must not be supposed, however, that with all the above mentioned advantages, the single-phase system has no disadvantages, as such is not the case. The car equipment, due to the transformers and the nature of the motors, is considerably heavier. The motors themselves are more expensive on account of their special construction. The equipment is not always adapted for operation on existing lines. There is a slight increased "apparent" resistance of the trolley line and a considerable increased "apparent" resistance of the rails, due to reactance caused by the alternating nature of the current. There is also an active electro-motive force between the field coils, which is objectionable, and there is a possibility of interference with neighboring telephone lines. Furthermore, there is slight loss in power in the transformers on the car, while the power-factor of the motors is less than unity.

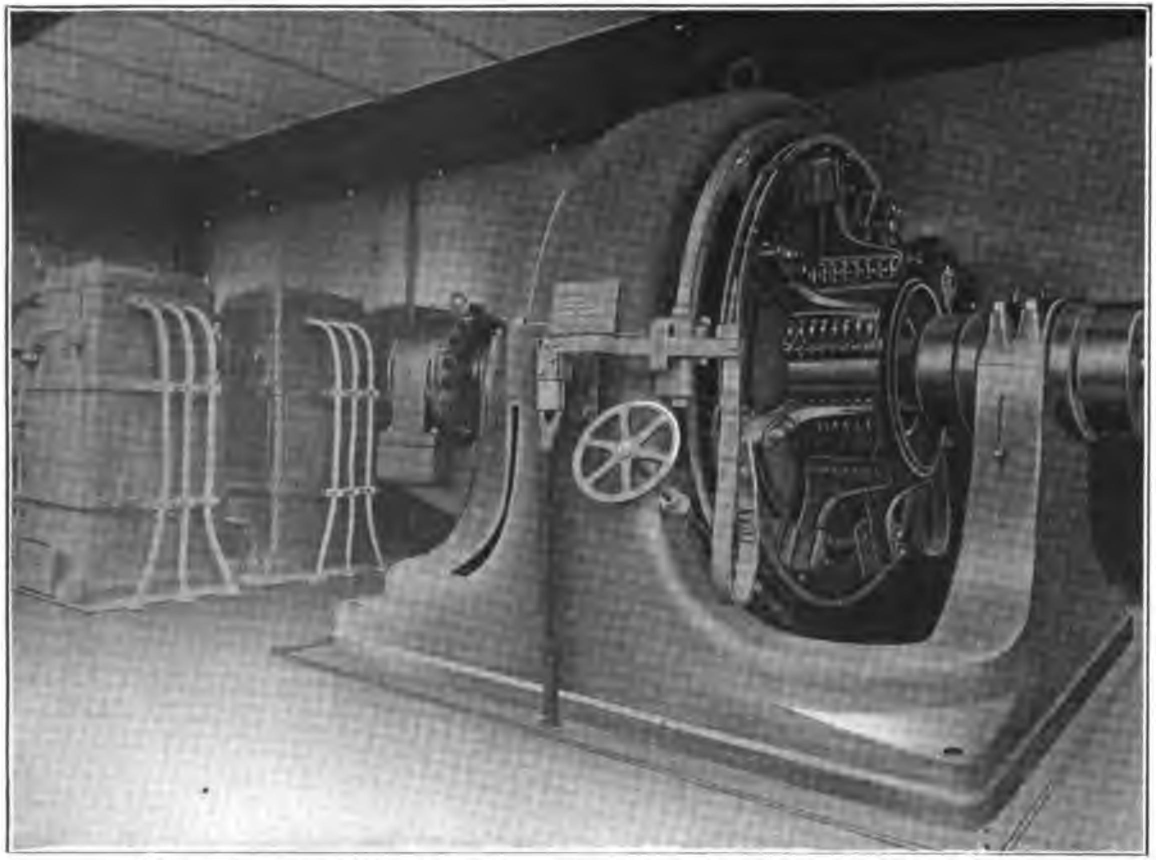
Summing the matter up as a whole, however, the advantages seem to overbalance the disadvantages, at least for many kinds of work, and it is safe to predict that this new system of operation will have a very wide and increasing application in the near future.

As to the operation of the system in general, the current may be developed by single-phase, two-phase, or three-phase generators, and supplied to the transformer substations just as it was formerly supplied to the rotary converter substations. Only a single phase is used on any section of the trolley line. The voltage on this transmission line will depend upon the existing conditions, and can be figured out like any other problem in power transmission.

Three-phase generators would ordinarily be used, as less copper is required to supply a given amount of power. The common frequency is 25 cycles per second. At the transformer stations, the voltage is then stepped down to that required on the trolley, which may be 2,000, 3,300, 6,600, or even 11,000 volts. While we cannot speak yet of a standard voltage, 3300 seems to be finding considerable favor. The voltage for which the motors are wound is 200 or 250, the General Electric motors using the former voltage, and the Westinghouse the latter. When operating on alternating current the motors are connected in parallel, and when running on direct current they are connected in series. Motors have been constructed from 50 to 225 horsepower, and there is no apparent reason why larger ones could not be made to operate with equal satisfaction.

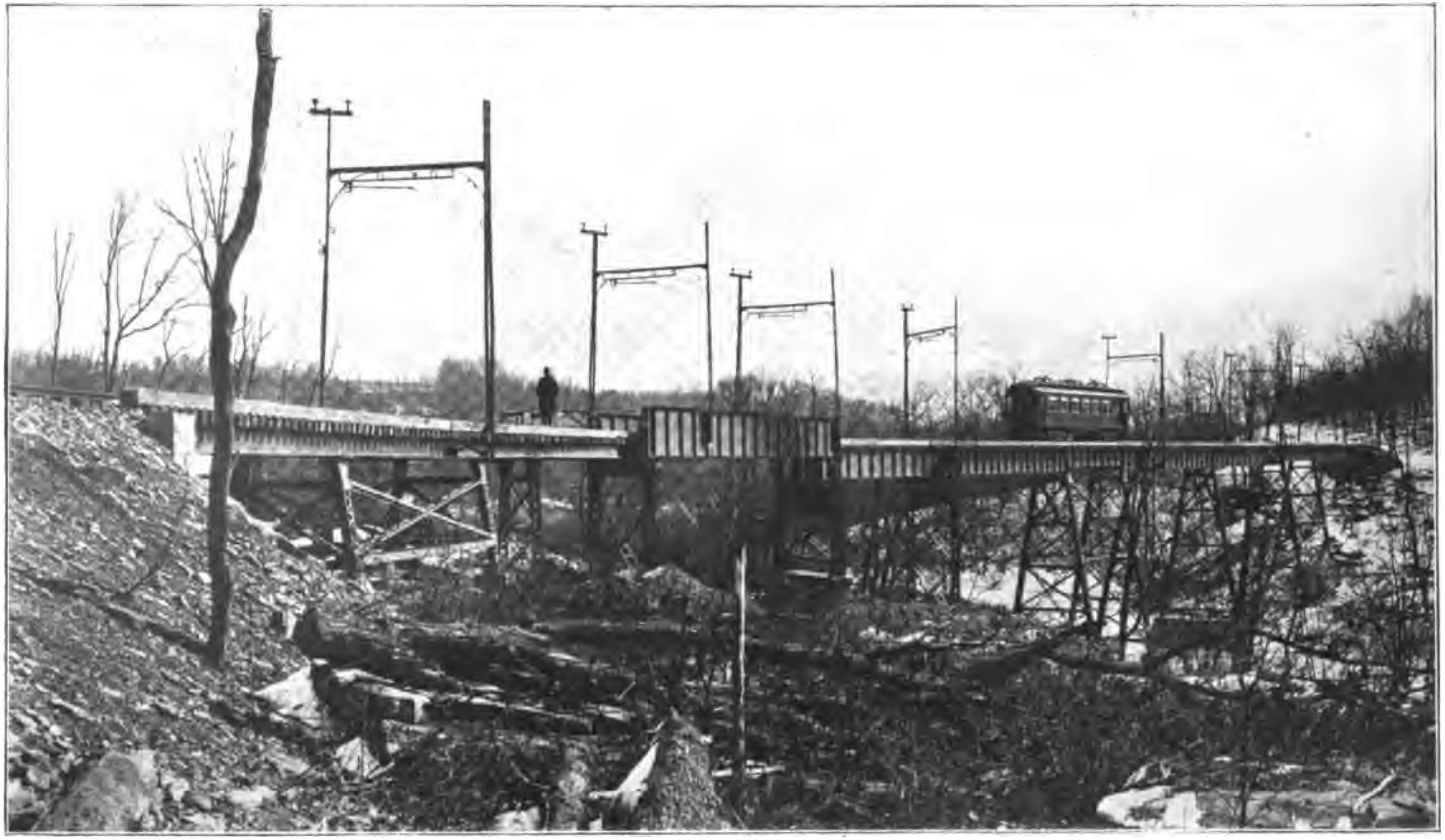
Truck Complete with Single-Phase Motors and Contact Shoes.

Among the roads in this country which are either using, or planning to use single-phase current, may be mentioned the Ballston-Schenectady line, which was one of the first systems to be equipped



800 K.W. THREE-PHASE ROTARY CONVERTER AND AIR BLAST TRANSFORMERS.

Manhattan Railway Company, New York City.



VIADUCT OVER THORN CREEK ON THE PITTSBURG AND BUTLER SINGLE-PHASE RAILWAY
Note the Line Construction.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.

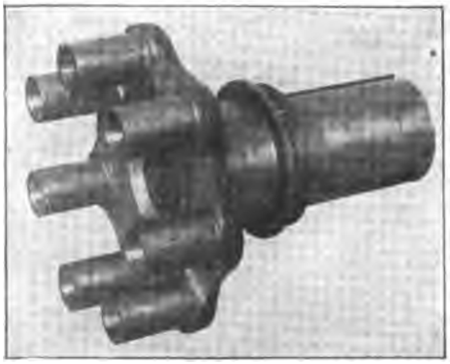
and has been in successful operation for some time. This road uses the alternating-current motor developed by the General Electric Co. The motors are adapted for operation on the 2,000-volt alternating-current trolley between cities, and on the standard 600-volt direct current in Schenectady. They are wound for 400 volts, and are operated in series on the 600-volt direct current. The frequency used is 25 cycles. Current is supplied by an overhead trolley, no feeders being used.

Magnetic Speed Indicator.

A second road of importance is one in Georgia between Atlanta and Marietta, which is 15 miles in length. This uses the Westinghouse equipment. The current on the trolley is 2,200 volts and 25 cycles. It is transmitted at a voltage of 22,000.

Another road of importance is the Indiana and Cincinnati interurban line, 41 miles in length, which has been in operation on regular schedule since July 1st, 1905. For 37 miles the road is operated from alternating current, and for 4 miles, from direct current. Four 75-horse power motors per car are used, capable of a maximum speed of 65 miles per hour.

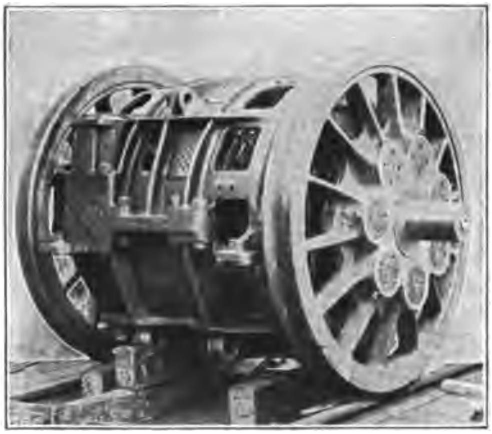
The Bloomington, Pontiac and Joliet Electric Railway is a single-phase road equipped with General Electric apparatus, and has maintained a regular schedule over a distance of more than 10 miles since March, 1905.



Armature Quill.

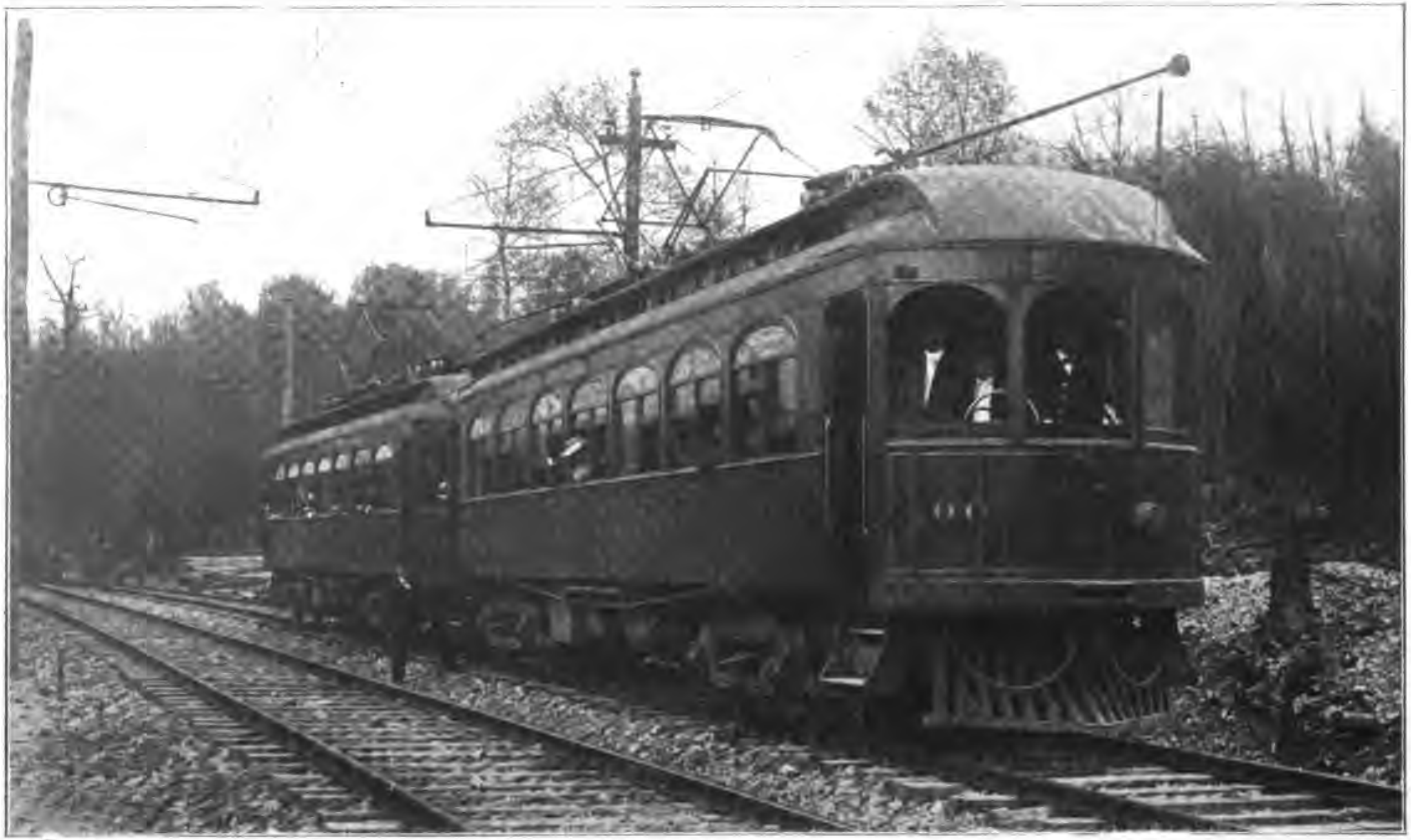
The plans are now being laid for a single-phase road, which will run south from Spokane, Washington, a distance of 150 miles. The current on the transmission line is 45,000 volts, which is stepped down to 6,600 on the trolley. The car will be capable of operating on current from a 6,600-volt alternating, a 700-volt alternating, or a 575-volt direct-current supply.

Perhaps the most important move which has been made in the direction of single-phase traction thus far is the decision of the New York, New Haven, and Hartford road to establish a long-distance passenger traffic on the single-phase system. According to the latest plans this road will operate between the Grand Central Depot and Woodlawn, N. Y., over the terminal tracks of the New York Central road, on direct current taken from the trolley. From Woodlawn, N. Y., to Stamford, Conn., the road will be operated on the single-phase system.



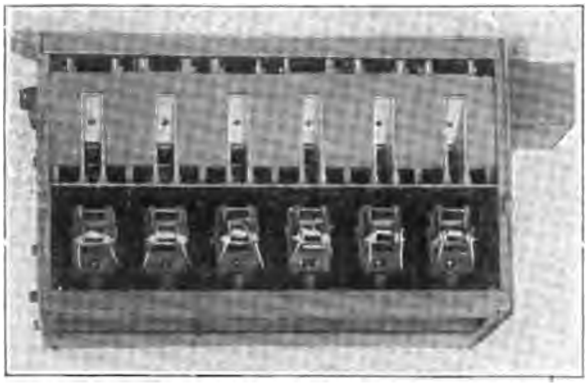
A Pair of Drivers with Single-Phase Motor Mounted upon Quill.

The equipment is being supplied by the Westinghouse Co. The current is generated by revolving-field type turbine-driven alternators. The armatures are designed for either three-phase or single-phase connection. The current is generated at 25 cycles and 11,000 volts, being delivered directly to the trolley, and thence to the cars, without the intervention of any transformers. The double catenary suspension from messenger wires is used to support the trolley. The locomotives are each equipped with four 200-H. P. gearless motors, designed to operate on 235-volt alternating current and 275- to 300-volt direct current.



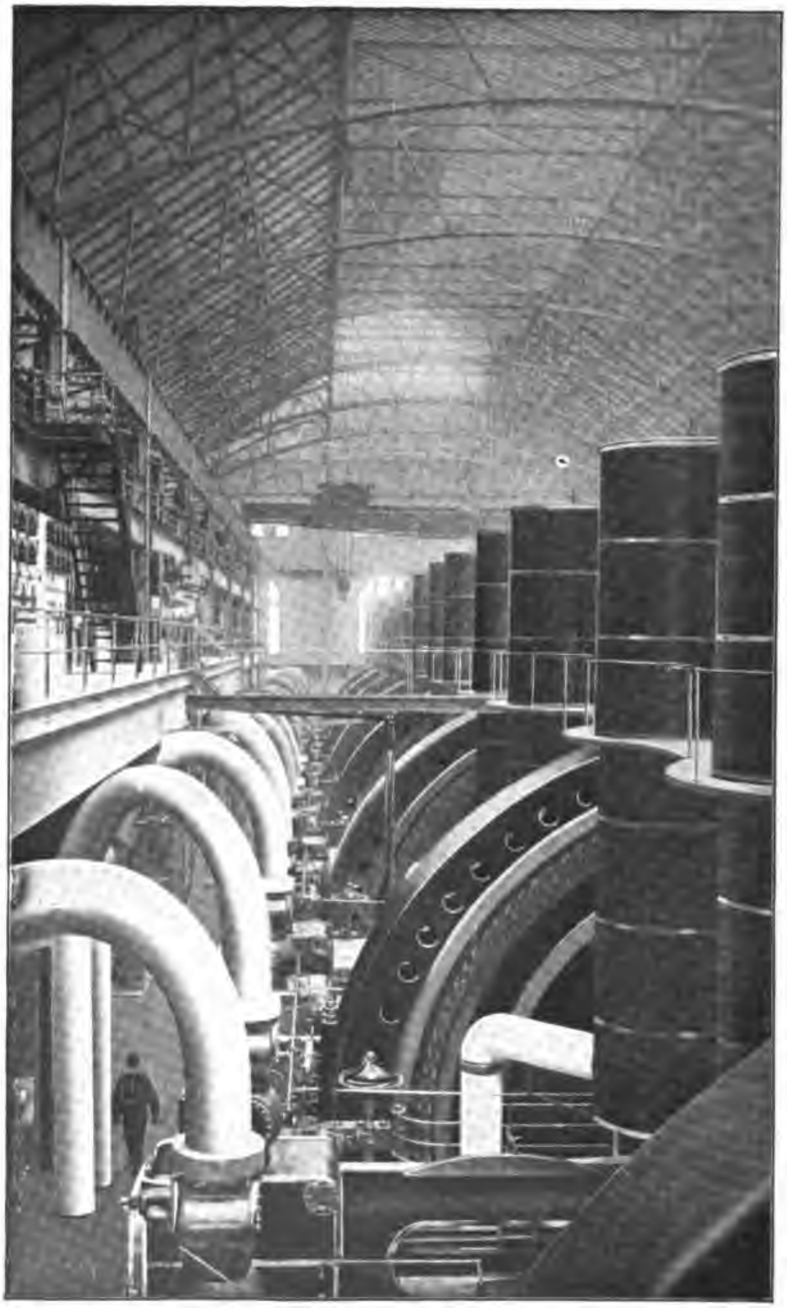
TRAIN OF TWO MOTOR CARS, PITTSBURG AND BUTLER SINGLE-PHASE ELECTRIC RAILWAY
They Operate on 6,600 Volts A. C. and 550 Volts D. C.
Westinghouse Electric & Manufacturing Co., Pittsburg, Penna.

The armature is not mounted on the shaft direct, but is built upon a quill through which the axle passes with about ⅝-inch clearance all around. There is a flange at each end of the quill from which seven pins project and fit into the hubs of the driving wheels. On the direct-current part of the line, current is delivered to the car through eight collecting shoes from a third rail. On the alternating-current section, current is delivered through two pantograph bow trolleys. On the direct-current section the series-parallel method of speed control is used, current being fed directly to the motors which are connected two in series permanently and the series-parallel control is applied to the motors in groups of two. The alternating-current speed control is accomplished by six taps from an auto-transformer for the corresponding running points. The cars weigh 78 tons and are capable of a speed of 60 to 65 miles per hour. The electro-pneumatic unit-switch type of control is used. At each end of the cab is a master controller from which the main controller is operated. Several locomotives can be operated together on the multiple-unit system, if desired.



Six-Unit Switch Group, Single-Phase System.

The Washington, Baltimore and Indiana single-phase road is the latest in the field, contracts having been placed very recently. The current will be transmitted at 33,000 volts and 25 cycles, then being stepped down to 6,600 volts on the trolley. The road will be 60 miles long and will be equipped with General Electric apparatus. Four 125-H. P. motors capable of operating on either alternating current or direct current will be used, and the cars will be capable of a speed of 60 miles per hour.



MANHATTAN 74th ST. POWER STATION, NEW YORK.

Showing Carey's Carbonate of Magnesia Pipe Coverings. Steam Connections.

A QUARTER CENTURY OF AMERICAN CENTRAL STATION ENGINEERING.

Perhaps few of the younger generation engaged in the various branches of electrical work realize that the central-station industry, so large and permanent an institution of our present civic life, is barely a quarter of a century old. Marvelous, indeed, has been the progress of this industry, and its wheels of invention and development are stilling whirling rapidly on. No engineer who values his reputation would venture to prophesy what the next quarter-century will bring us.

Twenty-five years ago the commercial electric lamp was unknown. To-day there are in service in the United States alone nearly twenty million incandescent lamps, to say nothing of the tens of thousands of arc lamps and the few hundred thousand horse-power in electric motors. To-day nearly every city of any importance in America has an electric plant furnishing light and power to its citizens. Magnificent stations have sprung up in our large cities, representing millions of dollars in investment; and electricity is being distributed to nearly every corner of those cities. It may be of interest, then, to look back over the history of this industry, and see some of the steps by which it reached its present splendid growth.

In all the world's history of industrial progress, perhaps no chapter is more full of scientific and heroic romance than that dealing with the birth of the electric-light industry. To the youth of to-day no story could give greater inspiration than that of the men who were the leading figures—the great minds and the energetic workers—during the early days of central-station development. These men contributed as much toward the nation's growth as did our warriors and our statesmen. Most of them are still with us, and are still active in solving engineering problems. It was the good fortune of the readers of the *Electrical World and Engineer* to see, in its recent thirtieth anniversary issue, some interesting reminiscences of these early workers, and thus have brought home to them the youthful age of the industry. It is not the purpose of this paper, however, to relate biography, but rather to treat of the more prosaic subject of the growth of the central station from its small beginnings to the magnificent proportions of to-day.

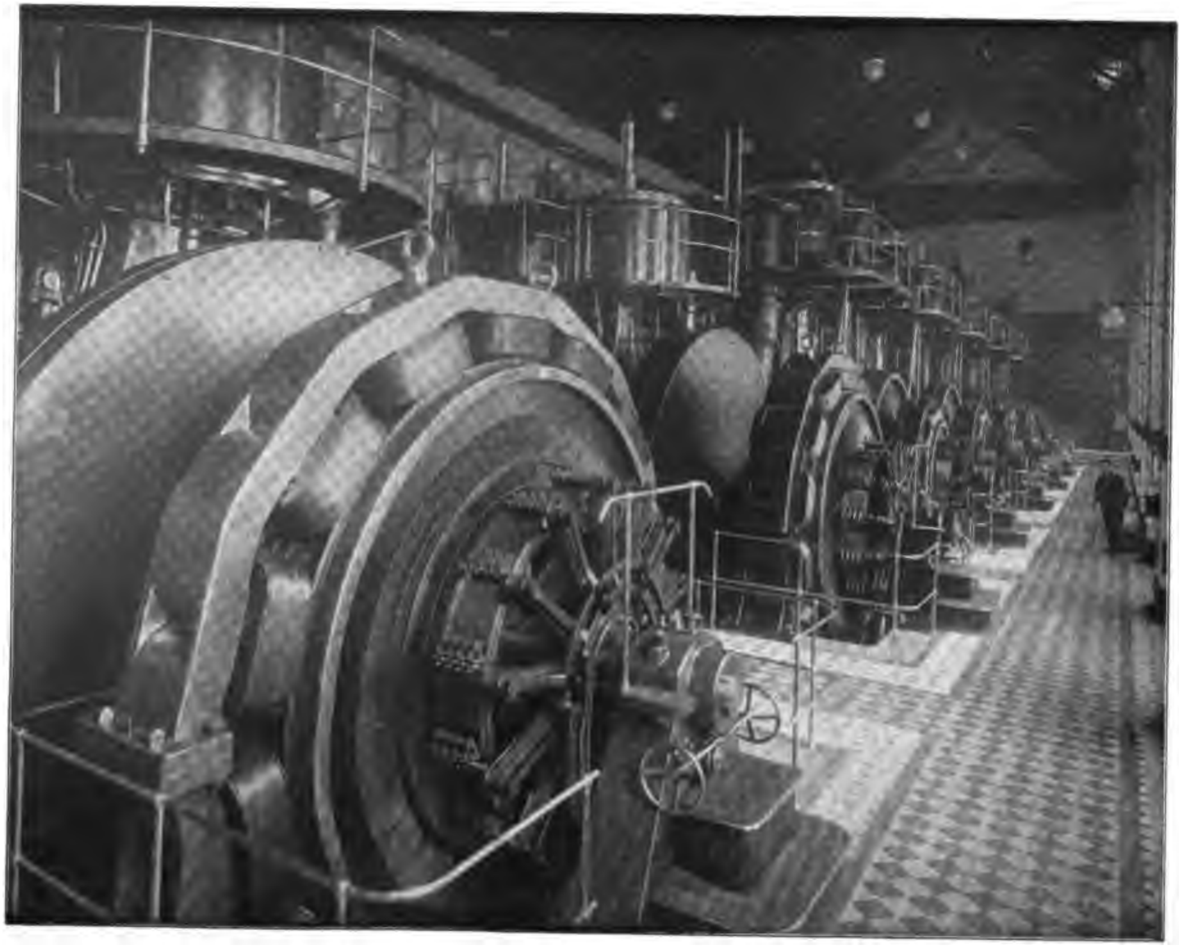
BRUSH ARC SYSTEM.

In 1879, there was erected in Cleveland, Ohio, a series-arc system designed by Charles F. Brush. The dynamo furnishing current for these lamps had been built by Brush during the preceding year. The electric arc itself had been discovered by Sir Humphry Davy in London about the year 1802, the source of current for his lamp being a battery of several thousand cells. As the dynamo had not at that time come into existence, the commercial importance of the discovery was not then apparent.

From this first system of Brush's, dates the history of commercial electric lighting in America. As stated, the lamps of this system were all connected in series, so that the same current passed through all of them. With many lamps on the circuit this required a fairly high voltage. The efforts of many investigators were then directed toward developing an incandescent lamp for these circuits so that the lights could be used indoors where the arc lamps would be too brilliant. In order to obtain a lamp requiring only a low voltage, which is a desirable feature in series connection, a lamp of low resistance is necessary.

EDISON CONSTANT-POTENTIAL SYSTEM.

The master mind of Thomas Edison soon saw that a series system with high voltage on each line would never become commercially successful for general house lighting; therefore he set about to design a system which should properly meet the required conditions. On February 5, 1880, he patented a constant-potential system consisting of feeders and mains, with the load connected in parallel, or multiple arc, between the two wires forming the positive and the negative conductors, as shown in Fig. 1. How well this succeeded is evidenced by the present almost universal use of this system of connection. Obviously, a low-resistance lamp would not do on a constant-potential circuit; Edison, therefore, first developed a high-resistance lamp. His success in this is well



Hamburg Central Power Station

Hamburg, Germany

known. His patent for the lamp is dated November 4, 1879. In December of that year he had a number of these lamps on exhibition at his laboratory in Menlo Park, and the following year he equipped his house and grounds with the lamps. The newspapers of the time were filled with accounts of what the "Wizard of Menlo Park" had accomplished, and visitors flocked to the town in great numbers to see the lights.

The first Edison plant for the public supply of current was located at Appleton, Wisconsin, where in 1881, was installed one of the first of the lanky bipolar dynamos, connected by a belt to a water wheel in a little wooden shed. The first central station for general distribution of current to incandescent lamps was started January 12, 1882, at Holborn Viaduct in London, England. The second and the third Jumbo dynamos (so named because of their bulk), built by Edison in America, furnished the current for this system. They weighed twenty-three tons each, and had a combined capacity of 3,000 lights. The first of these machines built by Edison was sent to the Paris Exposition of 1881. By October, 1882, the Edison Manufacturing Company had installed in all 123 plants, with a total of about 22,000 lamps.

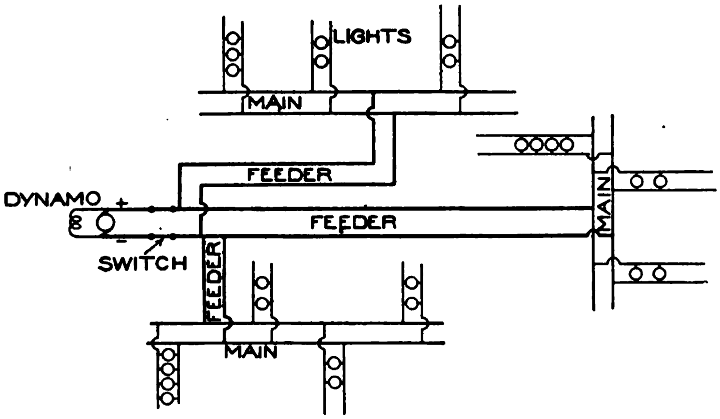


Fig. 1.

The Edison Tube. During this time Edison's attention had been directed toward laying out a system for the city of New York. In such a city it was desirable to have the system underground. Accordingly, the Edison tube was designed. This consisted of two half-round copper bars laid in iron pipe in lengths of about twenty feet, and insulated by means of a tar compound While there are still many miles of these tubes giving good service, all new underground work has for some years been done with lead-covered cables drawn into ducts laid in the streets, the connections being made in manholes. Fig. 2 shows a duct system made of cement-lined iron pipe laid in a bed of concrete.

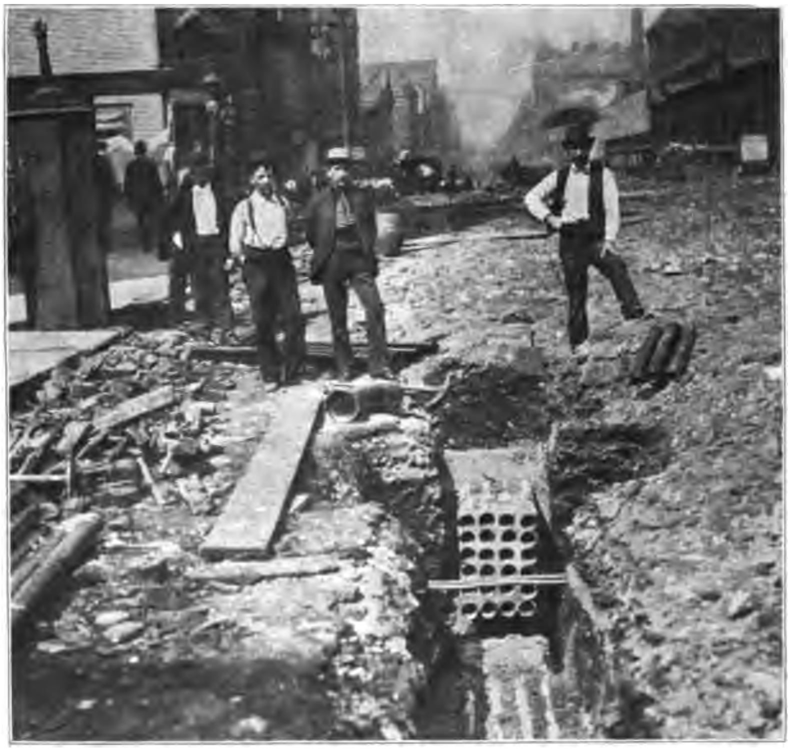


Fig. 2.

Three-Wire Direct-Current System. Late in 1882, Edison made a series of experiments with a view toward a more economical distribution system, and he then devised the well-known three-wire system, in which two generators are connected in series, and a conductor is connected to their junction, and run out into the system as the neutral wire. This is illustrated in Fig. 3. By connecting the lights so that the load on the two sides of the system is nearly balanced, a saving of about sixty per cent was effected in the amount of copper necessary to transmit the same energy. This is due to the fact that, in the three-wire system, the current is transmitted at 220 volts instead of at 110, thus requiring for the same number of watts only half as many amperes; and therefore a smaller wire can be used. If the load on the two sides of the system is not balanced, the difference between the current in the positive conductor and that in the negative will come back to the dynamos over the neutral wire. Dr. John Hopkinson, in England, and Werner von Siemens, in Germany, devised similar systems at about the same time.

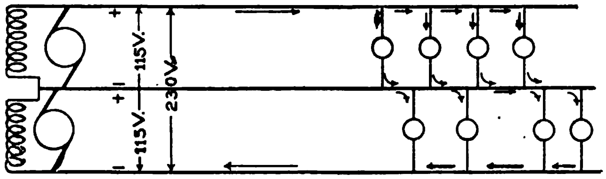


Fig. 3.

It was not until 1884 that electric motors were first used in New York; and the arc lamp designed for parallel connection on the constant-potential circuit was not introduced until 1889. The success of the constant-potential arc lamps made it possible for central stations to do all classes of business with one system of distribution—which was an important step in the march of progress. In 1890 the Duane Street Station was built in the heart of the Edison system, with a total engine capacity of 11,800 H.P. in direct-connected units.

In Boston, the Edison Electric Illuminating Company was organized in December, 1885, and the first station was started in February of the next year, using the Edison three-wire system of distribution. In 1887, a second station was built to take care of the load in another section of the city. Here, for the first time, was adopted the method of using 220-volt motors on the Edison system, connecting them to the two outer mains instead of between one outer and the neutral (110 volts), as had heretofore been done.

The Edison Companies. The good financial showing made by this company led to the formation of Edison Companies in many other cities, among the largest of which were Chicago and Philadelphia; and to the building of two up-town stations in New York. The original plant of the Western Edison Electric Light Company (now the Chicago Edison Company), a view of the dynamo room of which is shown in Fig. 4, was built at 139 Adams Street in 1887, and contained at first eight 100-K.W. Edison bipolar dynamos belted to four 250-H.P. engines located on the floor below. In 1891, additional dynamos and engines were added, until the total capacity reached 3,400 K.W.

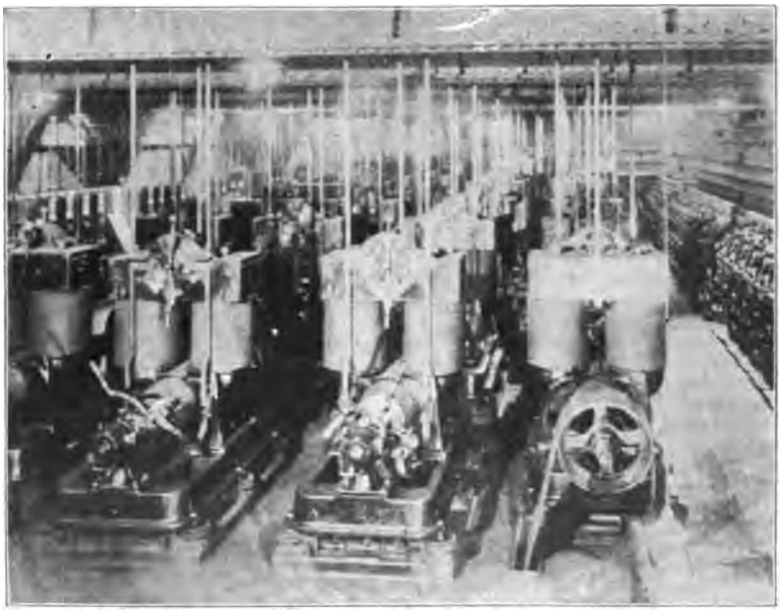


Fig. 4. Dynamo Room, Old Adams St. Station, Chicago Edison Co.

In the summer of 1892, the big station at Harrison Street, representing the most modern central-station engineering of the time, was started; and the next year the Adams Street Station was dismantled. The center of distribution, however, was kept at Adams Street, the current generated at the new station, about 3,000 feet away, being sent to this center over a trunk line consisting of twenty-eight Edison tubes and cables with a total sectional area of 66,000,000 circular mils. Of this, 9,000,000 c.m. of section was used for the neutral conductors, leaving 28,500,000 c.m. for each of the outsides, that is, for the positive and the negative.

In its onward march the Chicago Edison Company absorbed a number of plants, chief of which was that of the Chicago Arc Light & Power Company, located at Washington Street and the river. The systems operated from this station at that time consisted of series arcs, 500-volt direct current for power, and some 133-cycle 1,000-volt alternating-current lines. In 1894, there were added the Wabash Avenue Station near 27th Street on the South Side, with an Edison three-wire system and some series-arc lines; and the North Side Station at Clark and Oak Streets, which consisted solely of Edison generators connected to the usual three-wire system (Fig. 5). Fig. 6 is a view of the switchboard at Harrison Street Station. Fig. 6*a* is a back view of the generator gallery of this board, and shows the heavy copper bus bars. Fig. 7 is a cross-section of the engine and boiler rooms at Harrison Street Station, and Fig. 8 shows one of the 1,200-H.P. Southwark engines direct-connected to two 115-volt 400-K.W. generators. One of these dynamos connects with the positive, and the other with the negative, of the three-wire system.

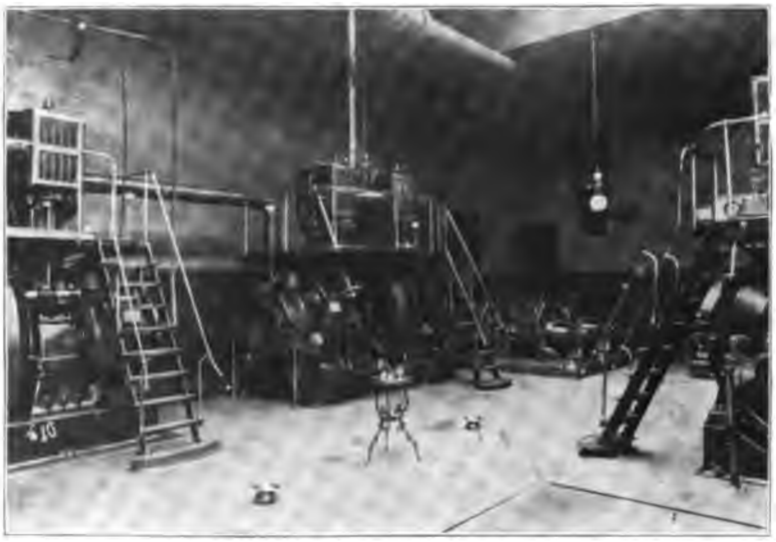


Fig 5. North Side Station, Chicago Edison Co.

Conservative Brooklyn waited to see what success was met by electric-light companies in other cities before its capitalists em-

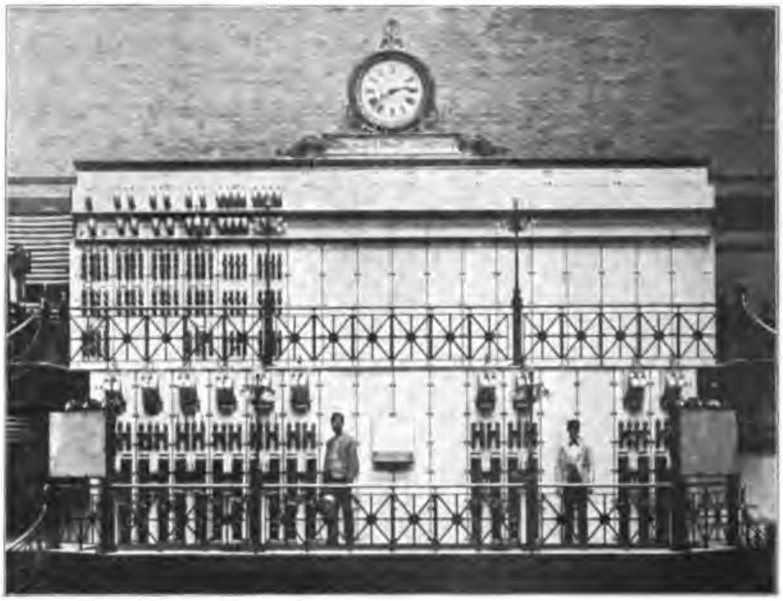


Fig. 6. Switchboard at Harrison Street Station.

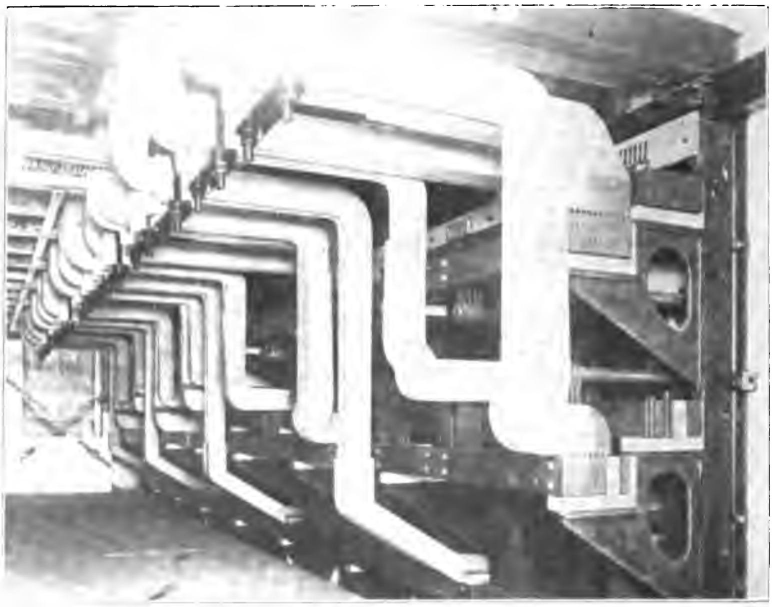


Fig. 6a. Back of Generator Gallery, Harrison Street Station.

barked on such enterprises, but in 1889 that city was added to the list of those having a central station for the production of electricity. In that year the Edison Electric Illuminating Company of Brooklyn built its first station on Pearl Street, and started operations with a load of 6,600 incandescent lamps connected to the system. The dynamos used were four of the Edison bipolar type of 100-K.W. capacity, each two of which were belted to a 250-H.P. cross-compound engine and were connected to an underground three-wire distribution system. In 1893, the station was remodeled, and larger dynamos were introduced direct-connected to vertical cross-compound condensing engines.

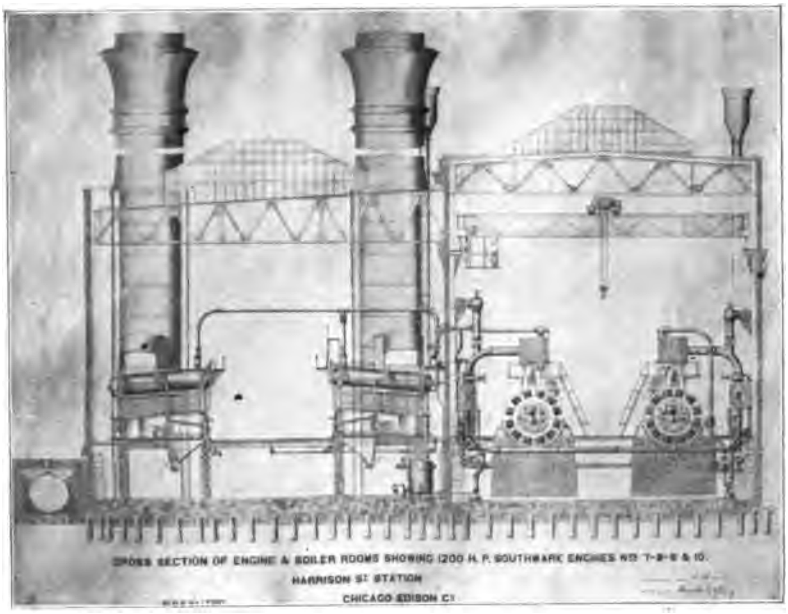
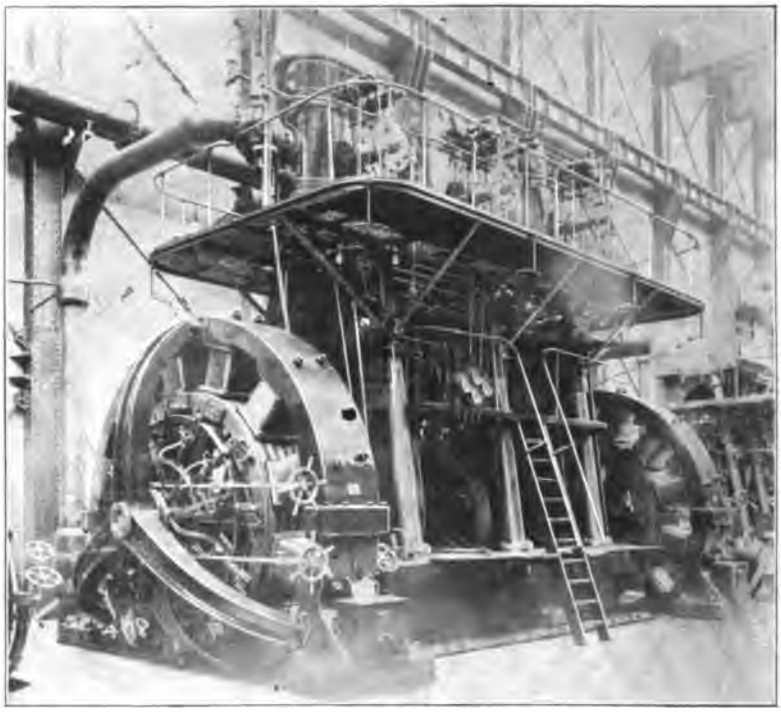

CROSS SECTION OF ENGINE & BOILER ROOMS SHOWING 1200 H. P. SOUTHWARK ENGINES NO 7-8-9 & 10.
HARRISON ST STATION
CHICAGO EDISON CO

Fig. 7. Cross-Section of Engine and Boiler Rooms, Harrison Street Station.

ALTERNATING-CURRENT SYSTEMS.

The development of the alternating-current system in America is due largely to Mr. George Westinghouse, who, in 1885, had built at Pittsburg, Pa., an experimental plant to work out the system devised by Gaulard and Gibbs in England. The first commercial result of the Westinghouse investigations, carried on



Fig, 8. 1200 H.P. Southwark Engine and 400 K.W. Generator.

by Shallenberger, Stanley, and others, appeared in the plant installed at Buffalo, N. Y., in November, 1886. The following year, 65 plants, with a total capacity of 125,000 lights, were built, and the increase thereafter was rapid.

With a direct-current three-wire system using 230 volts between outside conductors, it is uneconomical to transmit current much farther than one and a half miles, because of the prohibitively large amount of copper necessary to keep down the loss in the feeders. The resistance of a conductor varies with the length; and as it requires the expenditure of energy to send a current over a resistance, obviously a high resistance means a large amount of energy lost in the transmission. By increasing the cross-section of the feeder, this resistance can be kept low; but the cost of the feeder would then be prohibitive. By means of the alternating-current system with static transformers, connected as shown in Fig. 9, energy can be transmitted at a much higher voltage from the station. The higher the voltage of transmission, the smaller will be the current (amperes) for a given energy (watts); therefore with the high-voltage system, a given energy can be transmitted over a much smaller wire than would be required for that same energy at a low voltage. In the transformers placed at or near the point where the current is to be used, the pressure is "stepped down" to the voltage of the lamps on the circuit.

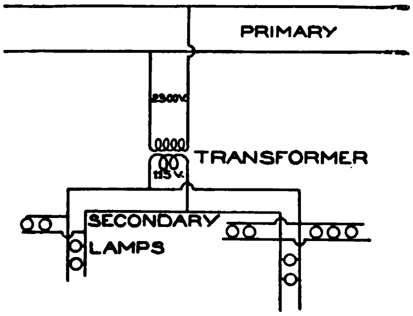


Fig. 9.

The regulation—that is, the steadiness and constancy—of the voltage of these alternating-current lines, was very much poorer than that of the direct-current system. This was largely due to the effects of self-induction, which is ever present with alternating currents. The early incandescent lamp used on the direct-current 110-volt systems was rather delicate, and had only a short life when burned on a circuit in which the pressure fluctuated very much. Consequently, it could not be used economically on the existing alternating-current lines. A 50-volt lamp could be made far more stable, and, largely because of this, the secondaries of the early transformers were wound for 50 volts. The primaries were wound for use on 1,000-volt circuits—which was then considered as high as desirable, because of the difficulties of insulating the line, the transformers, and other apparatus on which this voltage was applied. Rapid advance, however, was made in the art of insulating, and soon this primary pressure was doubled. Most of the city A. C. distributing systems now have a primary pressure of about 2,300 volts. It is interesting to note that the insulators used on the early European high-tension lines were constructed with a trough along the edge on the inner side, which was filled with oil in order to prevent current leaking over the surface of the insulator to the pin and thus to ground, by way of the cross-arm and pole, on wet days.

One of the larger of the early stations for the generation and distribution of alternating current was built in St. Louis, Mo., in 1889. The system adopted was single-phase, 1,200 volts, 60 cycles*, with a three-wire Edison system for the secondaries. These secondaries were tied together at street crossings, forming a complete network similar to that described for the direct-current system, and shown in Fig. 10. In this case the feeders of the D. C. system were replaced by the high-tension A. C. feeders and transformers, the latter being treated as part of the feeders. Pressure wires were connected to the secondaries of the transformers, and were run back to the station voltmeters to be used by the switchboard operator in regulating.

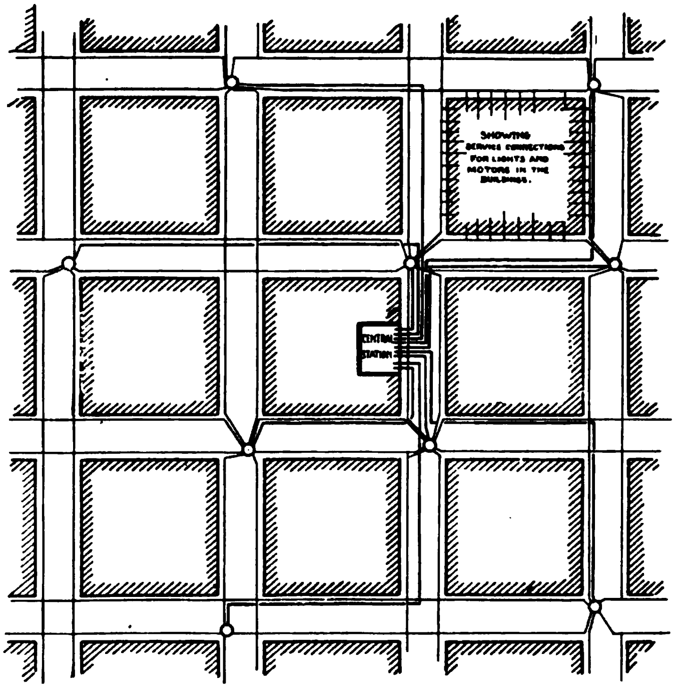

SHOWING SERVICE CONNECTIONS FOR LIGHTS AND MOTORS IN THE BUILDINGS.
CENTRAL STATION

Fig. 10.

An interesting alternating-current line was built between San Bernardino and Pomona, California, in 1891. Here a transmission pressure of 10,000 volts was used, obtained by means of connecting the 500-volt primaries of twenty transformers in series. Thus each transformer had to have insulation for a working pressure of only 500 volts, which was comparatively easy to produce.

---

*NOTE. A current which alternates 120 times per second has 60 double alternations or "cycles" per second.

In 1891, the celebrated three-phase transmission line from Lauffen to Frankfort, in Germany, was operated. Originally this was intended for transmitting energy generated by water power at Lauffen, to the city of Heilbron, six miles away; but it was first used in the now famous transmission to Frankfort, a distance of 110 miles, at the time of the Frankfort Exhibition. The dynamo, built at the Oerlikon Works in Switzerland, was star-connected, and generated a star pressure of about 50 volts.

In a three-phase star-connected generator, the armature windings consist of three branches which are connected at one end to a common point. These branches are so placed on the armature core that the wave of the alternating pressure is set up in one coil a little later than is the wave of pressure set up in the coil immediately ahead of it, and a little sooner than the wave in the coil immediately back of it. These three pressures then follow each other in regular succession, the phase difference (the time between similar values of the different waves) being equal to one-third period.* The wires leading to the other ends of the three armature coils are called the "phase" wires, while the one connecting to their junction is the "neutral" wire. The pressure between a phase wire and the neutral is called the "star" pressure, while that between any two phase wires is called the "delta" pressure. This latter is 1.732 times as great as the star pressure. For greater safety in operation—principally to prevent abnormal rises in pressure between a phase wire and earth—the neutral wire is thoroughly "grounded" by being connected to a plate embedded in the moist earth.

The 50 volts pressure generated at Lauffen was "stepped up" by transformers of 8,000 volts, delta, at which pressure the current was transmitted.

DEVELOPMENT OF WATER POWERS.

After the success of polyphase transmission had been thus established, a great impetus was given to the development of water powers, and the following years found this system adopted by many companies. One of the first of these in America was built at Telluride, Colorado, in 1892. The original pressure used here was 3,000 volts, three-phase, straight from the generator. As a result of an extended series of experiments made on this line in 1896, much valuable data was obtained regarding high-tension transmission; and to-day there are many such systems, some operated at a pressure as high as 40,000 volts, which is the pressure now used at Telluride, while a few others are going still higher. The limit to-day seems to be about 60,000 volts, but even this may be increased as the art advances.

---

*NOTE. A period is the fraction of a second for one complete cycle of the alternating wave.

The Sacramento-Folson line, in California, built in 1895, originally transmitted 1,000 H.P. at 11,000 volts, three-phase. The generators were wound to give a pressure of 800 volts, and this was raised in transformers to 11,000 volts.

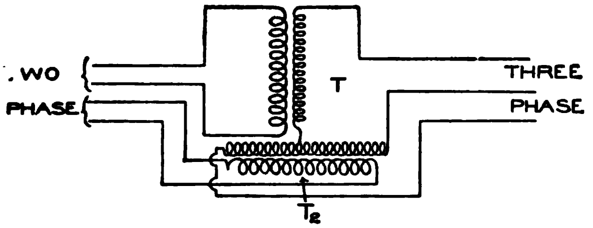


Fig. 11.

The Mechanicsville, N. Y., and the Snoqualmie Falls, Wash., plants are the most important three-phase transmission systems built in 1898. In the former, a transmission pressure of 12,000 volts, 38 cycles, was adopted; while in the latter, the generated pressure of 1,000 volts, 50 cycles, were stepped up to 25,000 volts.

Many of the polyphase stations built in the early nineties were equipped with two-phase generators. The two-phase currents were then stepped up and transformed to three-phase currents by means of a scheme of connections devised by Mr. Charles F. Scott. This connection is shown in Fig. 11. In this diagram, T and T_2 are two transformers, the primaries of which have the same number of turns and are connected to the two phases of the two-phase circuit. The secondary of T has only .866 times the turns of the secondary of T_2. By connecting one end of the secondary of T to the middle of the secondary of T_2, as shown, three-phase currents of equal pressures on each phase are obtained from these secondaries.

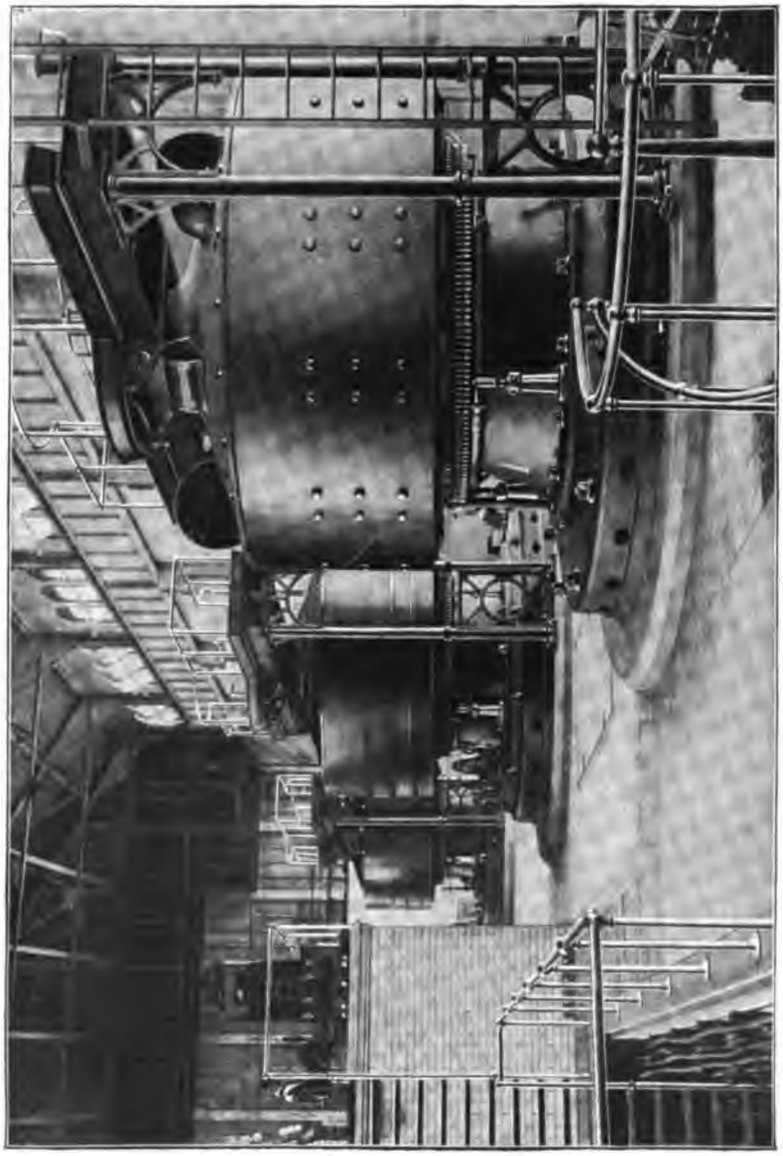


Fig. 12. Interior of Power House No. 1, at Niagara.

The best known example of this is the system at Niagara Falls, N. Y., where 25-cycle two-phase currents, generated at 2,200 volts, are transformed to three-phase currents at 22,000 volts, at which pressure the energy is transmitted to Tonawanda and to Buffalo, the latter being about twenty miles from the station. When this station was first operated, in 1896, the transmission pressure was 11,000 volts. Since that day many high-tension transmissions have sprung into existence; and the increase in voltage is keeping step with the improvement in insulators, as already noted. An interior view of Power House No. 1 at Niagara Falls is shown in Fig. 12.

FUNCTION OF THE STORAGE BATTERY.

While these important developments in cross-country transmission were under way, the engineers of the urban stations also had a few problems to solve. The convenience and other desirable features of the use of electric light and power were now being widely appreciated, especially when the cost of the lamps was reduced; and electric motors also were being used more liberally, in sizes from one-fourth horsepower to 300 H.P. and larger. This meant a big increase in the load on the station, as well as in the size of the district to be served. How to meet this increase economically, required an intelligent study of the problems of current distribution. As already noted, the distance over which it is economical to transmit current at a low voltage is limited; and, when the area to be served exceeds this limit, recourse must be had to more stations or to a higher distribution pressure. A study of the load curve of an average central station in a large city (Fig. 13) shows that the feeders are carrying their heavy current for but a short time each day. During all the remainder of the day, then,

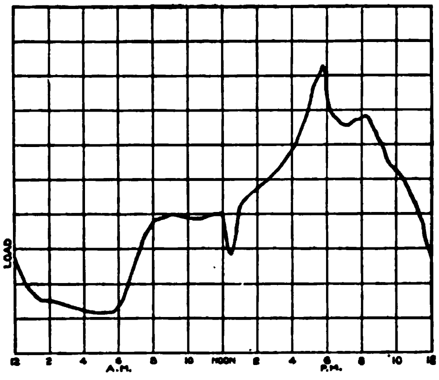


Fig. 13.

the current in these feeders is comparatively small; also, much of the generating capacity of the station is idle, representing just so much investment inactive and earning no returns. If now, during the period of light load, a current, additional to the regular load, can be sent over these feeders, and if this current can be stored in some way in a location within but near to the economical limit, so that it can be used at the period of heavy load, this storage substation will in turn become a point of distribution from which current can be sent out as far again as the economical limit. Here is where the storage battery filled the want. In 1894 we find storage-battery substations installed in Boston and New York, and soon after companies in other cities adopted them. In Boston, a number of battery substations were installed in the nearer outlying districts, all of them being connected with one another and with the steam station. The batteries are charged during the hours of light load by means of boosters, which form part of the substation equipment. Their usefulness, however, is not by any means limited to outlying districts. As an auxiliary to a generating station, it is considered good practice from the standpoint of economy to install a storage battery if the peak of the load does not exceed two and one-half hours. As a safeguard against interruption of service, and as a help in maintaining a uniform pressure on the system, they have been found almost invaluable.

CONSOLIDATION OF PLANTS.

The next step in the development was one of consolidation. Many cities had been liberal in granting franchises to lighting companies, and as a result there were built within the same city many systems of various excellence and stability. To the engineers of the consolidated company was then presented the problem of unifying the systems; but the changes to the new system had to be made without sacrificing the value of the investment represented by the generating apparatus and lines of the existing stations. Such a change, naturally, was made step by step, and thus required several years. In addition to providing for the existing load, the new system had to be designed for the future, and the probable development in the line of various classes of electrical apparatus had to be considered.

In our larger American cities, the load conditions can be divided into two general classes—one, in which a large load is concentrated over a comparatively limited area, which is the downtown or business district; and the other, the residence district, where the load is widely scattered over a large area. In the downtown district, nearly 30 per cent of the load goes to power users; therefore the system had to be adapted to all classes of motor service, as well as for lighting. For this service in such a district, the Edison direct-current three-wire system is certainly the most satisfactory, and this system has been pretty generally adopted. It permits the use of storage batteries; requires less copper than does the alternating-current system, because in it there is no loss due to inductance; gives better regulation; and is far better for general all-around power service.

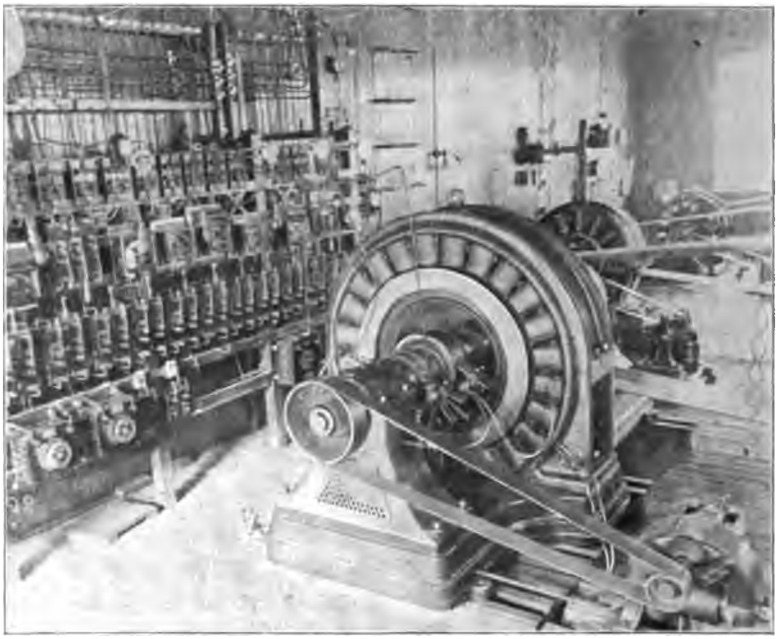
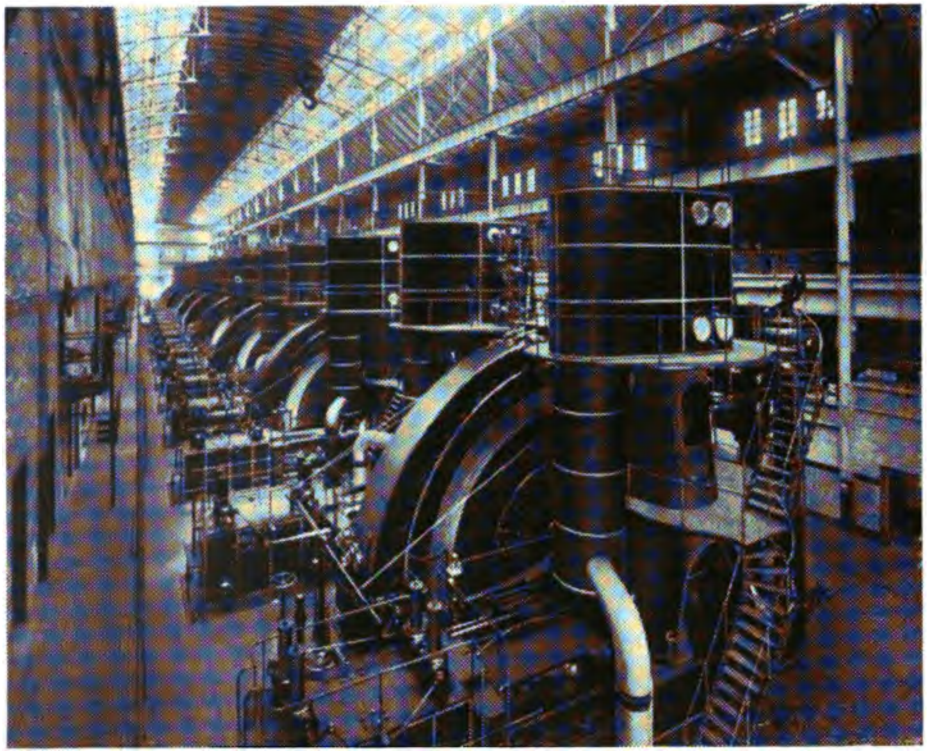


Fig. 14. Early Alternating-Current Station.

To consolidate several systems of this class was a simple matter. It required merely that the separate networks of mains be tied together, and a uniform pressure kept on the system by each



WESTINGHOUSE A. C. GENERATORS IN THE 59TH STREET STATION OF THE INTERBOROUGH RAPID TRANSIT CO., NEW YORK CITY

5,000-K. W., 11,000-Volt, Three-Phase, Engine Type, Revolving Field.

station feeding into it. In the outlying districts, however, the problem was more complicated. Because of the scattered load, most of the systems feeding these districts used alternating current. But there was a wide divergence in regard to frequency and voltage. Some of the lines were 1,000-volt; others, 2,000-volt. Some used a frequency of 125 cycles; others, 133 or even 144 cycles. The secondary pressure ranged from 104 to 125 volts, while some of the earlier systems still maintained a secondary pressure of 50 volts. A few of the later stations had 2,000-volt lines, with a frequency of 60 cycles; and there were also polyphase (generally two-phase) lines for serving a motor load. A view of an early alternating-current station is given in Fig. 14.

High-Voltage Polyphase Systems. This conglomerate mass, then, had to be unified. A careful study of various systems showed the four-wire three-phase system, with a frequency of 50 to 60 cycles, to be the best suited to the distribution of such a load; and this system is being freely adopted. Good examples of it are found in Chicago, Milwaukee, St. Paul, and Cincinnati. The generator for this system is star-wound, with the neutral grounded, as already explained. The voltage at which this system is generally operated is 4,000 between phase wires. This gives a pressure of approximately 2,300 volts between any phase wire and the neutral; and the single-phase lighting feeders are switched on to this 2,300-volt

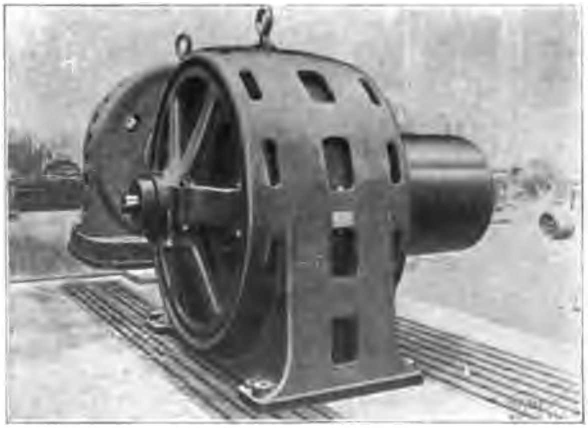


Fig. 15. Polyphase Induction Motor.

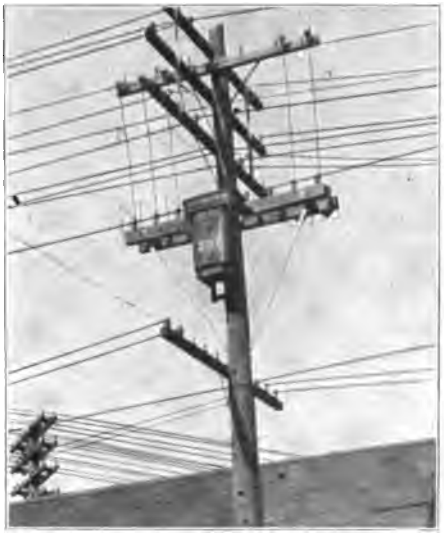


Fig. 16.

connection. The various feeders are connected each to one of the phases and the neutral, so that the three phases are approximately balanced. For a power load, then, connection is made to all three phases, and the motor is usually of the polyphase induction type, of which one is shown in Fig. 15. Where the capacity of the motor is very small—under 3 H.P.—the single-phase type of induction motor, equipped with some special starting device, is often used. Step-down of the voltage to the service pressure is, of course, accomplished by means of the ordinary 2,300-volt static transformers.

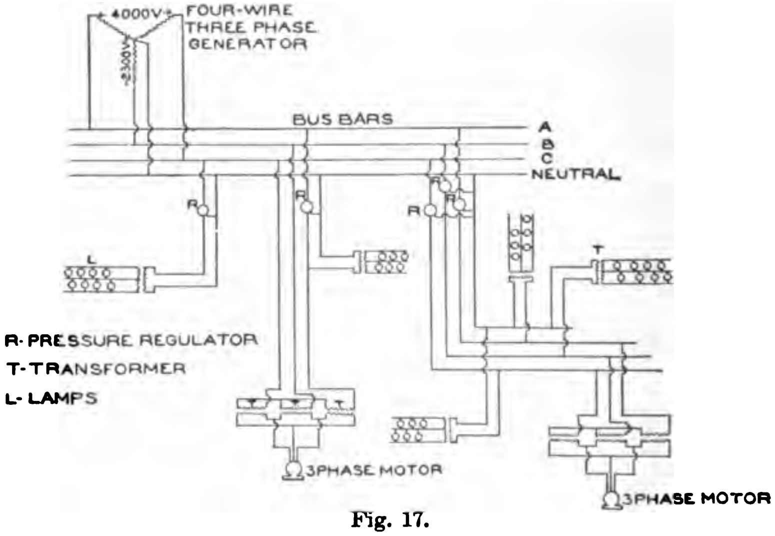


Fig. 17.

In Fig. 16 is seen a 150-light (7.5-K.W.) transformer on a pole. The two wires coming down at the right are the 2,300-volt primaries; while the three-wire secondaries, of 115 volts per side, are brought up at the left. A diagram of a four-wire three-phase distribution is shown in Fig. 17; and in Fig. 18 is seen a switchboard installed for such a system.

When the transmission distance is great, this three-phase pressure can be raised to any desired amount, and then stepped down again at the substation, the local distribution again being done on 2,300-volt single-phase feeders with a pressure of 4,000 volts between phase wires. In some cities, a two-phase system was adopted; while others, again, used the three-wire three-phase system (in which a neutral conductor is not used and all load is connected between phase wires). Brooklyn has a two-phase 2,300-volt 60-cycle system in the residence section; Philadelphia also, though in the latter city the current is generated at 5,500 volts and stepped down to 2,300 volts alternating-current distribution.

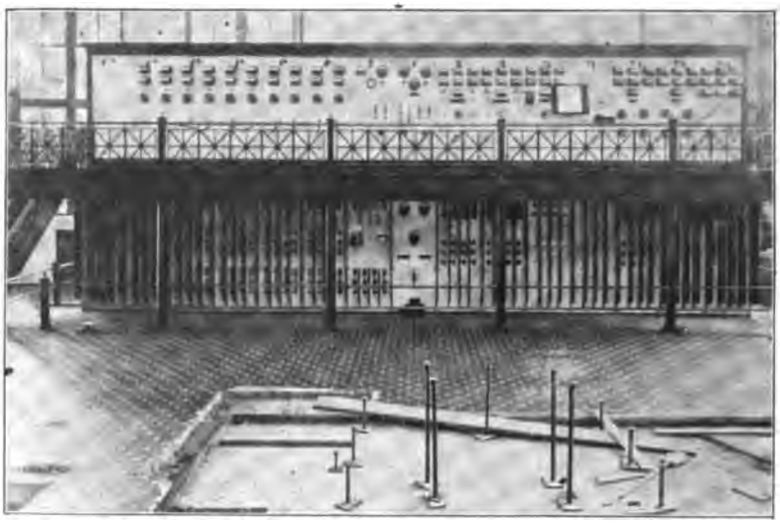


Fig. 18. Switchboard of 4-Wire 3-Phase Distribution System.

A 500-volt two-phase generator is shown in Fig. 19. For higher voltages the revolving-field type is used, thus avoiding collector rings and brushes for the high-voltage current. At the South Boston station of the Boston Electric Light Company (now part of the Boston Edison Illuminating Company), the generators are wound for 2,300-volt three-phase 60-cycle currents.

In the direct-current districts, the load often increased very heavily in sections somewhat remote from the generating or the distributing center; and then it became a question of more stations, more copper, or some other additional means of transmission. To provide enough copper for satisfactory transmission and regulation, would bankrupt a company. To build and operate a new generating station in each section of heavy load, would be equally ruinous. Consequently recourse is had to other means of transmission. The success and the comparative copper economy of polyphase transmission lines, already mentioned, showed that system to be the proper one to adopt; and the three-phase system was chosen as the means to transmit current to substations located at or near the electrical center of the load. Such a transmission system, from a large alternating-current station in preference to several direct-current generating stations, is considered good engineering whenever the total energy generated is large as compared with that used at any one locality. The voltage determined upon depended to some extent on the local conditions, but more largely on the efficacy of the insulation of underground cables, since in the cities all lines must be below the surface. In the early days of underground cables, 5,000 volts was thought very high pressure; to-day 25,000 volts is not considered excessive; and a recent article in the *Electrical Age* stated that an underground cable system will soon be installed, to be operated at 30,000 volts. The insulating material used in these high-tension cables consists of paper treated with a resinous compound, the thickness in the 30,000-volt cable

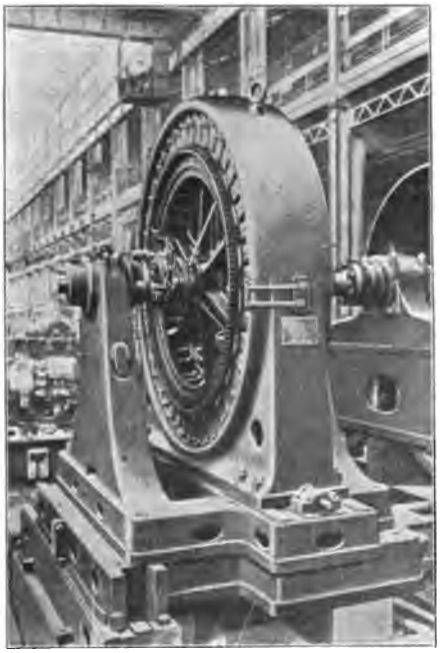


Fig. 19. 500-Volt 2-Phase Generator.

being about one-half inch. Over this is a lead sheath about ⅛-inch thick, to protect the cable against moisture and mechanical injury. These cables are drawn into ducts laid below the surface in the streets, as shown in Fig. 2.

One of the earliest instances of the use of a three-phase transmission to a substation, for conversion to direct current of an Edison system, was in Chicago, where, in 1897, a 250-K.W. inverse rotary converter, which converted direct current of 250 volts to three-phase 25-cycle currents was installed at the Harrison Street station. By means of step-up transformers, this pressure was raised to 2,250 volts, the pressure of the transmission. In the substation on Wabash Avenue, near Twenty-seventh Street, this voltage was stepped down again; and, after passing through the rotary converters, the current was fed into the direct-current system at 115 volts, one rotary being connected to each side of the Edison system. Such was the humble beginning of the very extensive system of high-tension transmission lines and substations, which, at quadruple the initial voltage, is now in operation in Chicago.

In the same year there was installed in Brooklyn, N. Y., a similar transmission system with a rotary converter substation. Here the current was generated at 6,600 volts, 25 cycles, three-phase, at the Union station, a similar system to that operated by the New York Edison Company. In the magnificent Waterside station of this latter company, there are at present eleven 5,500-H.P. vertical engines, each driving a 4,500-K.W. three-phase 25-cycle 6,600-volt alternator. A 5,000-K.W. Curtis turbo-generator is being installed, and there is room for four more. This will make a total rated capacity of 75,000 K.W., all power being generated as alternating current for transmission to rotary converter substations, from which it will feed into the Edison three-wire direct-current system. In the splendid new Fisk Street station in Chicago, 9,000-volt 25-cycle three-phase current only is generated, all by Curtis turbo-generators. Fig. 20 shows a Westinghouse-Parsons unit of 5,000 K.W. capacity.

In Philadelphia, the 5,500-volt two-phase 60-cycle system, already referred to, is used for transmission to rotary converter substations, as well as for the alternating-current distribution, Fig. 21 shows a row of rotary converters of a substation located in

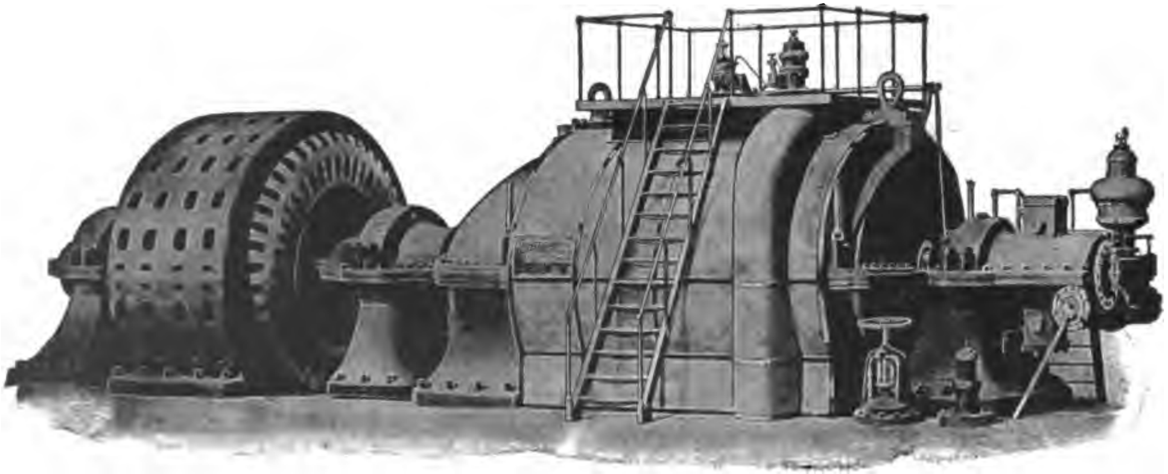


Fig. 20. WESTINGHOUSE-PARSONS 5,000 K. W. TURBINE GENERATOR.
For the Pennsylvania Railroad Tunnel, New York.

the basement of a sky-scraper in the heart of the business district of Chicago.

Where the load connected to transmission lines consists solely of substation converting apparatus, a low frequency is desirable because of the accompanying low inductive and capacity reactance of the lines, and also because of the slower speed of the synchronous motors and rotary converters which is had for a given number of field poles with a lower frequency. The higher the frequency, the greater the number of poles required, or the greater the speed. Because of the necessary number of commutator bars required between the brushes of a D. C. machine, and therefore also on a rotary converter, the distance between the centers of the pole pieces (that is, the pole " pitch ") cannot be less than a certain fixed limit; and, therefore, for a given speed, the lower frequency allows a far simpler and cheaper construction. The higher-frequency machines are also more liable to " hunt " especially when the load varies considerably. Furthermore, double-current generators having a commutator connected to the armature windings for direct current, and also having connections to collector rings from which alternating current is taken off, are not practicable for frequencies much above 25 cycles. These double current generators, producing both direct and alternating current at the same time, form a very valu-

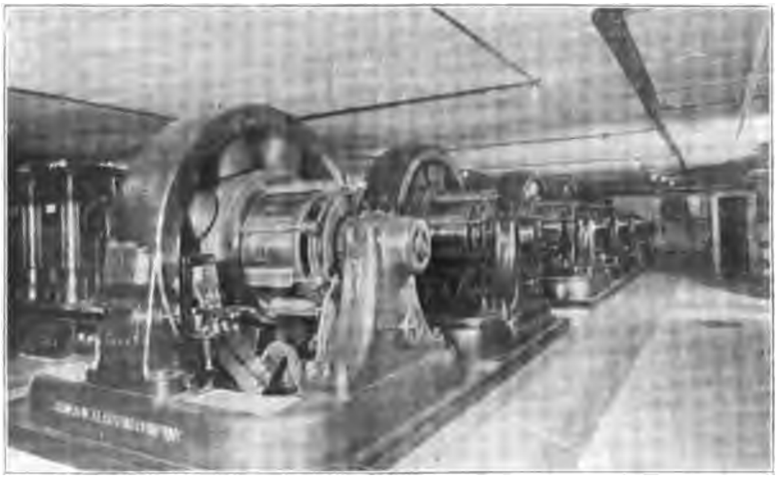


Fig. 21. Rotary Converters in Basement of Office Building.

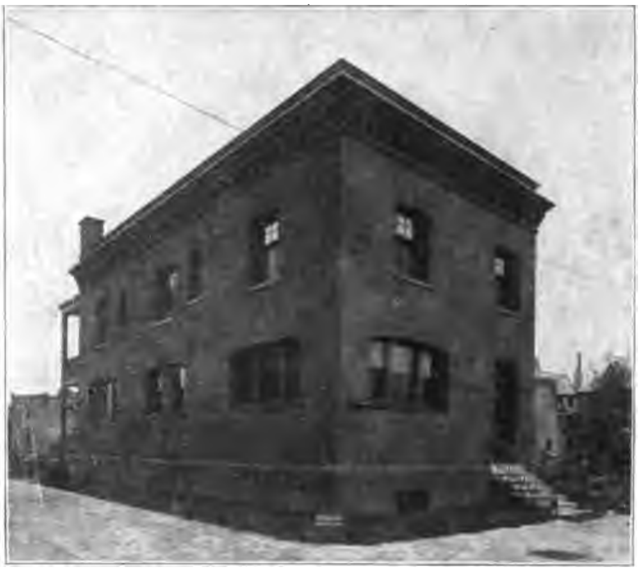


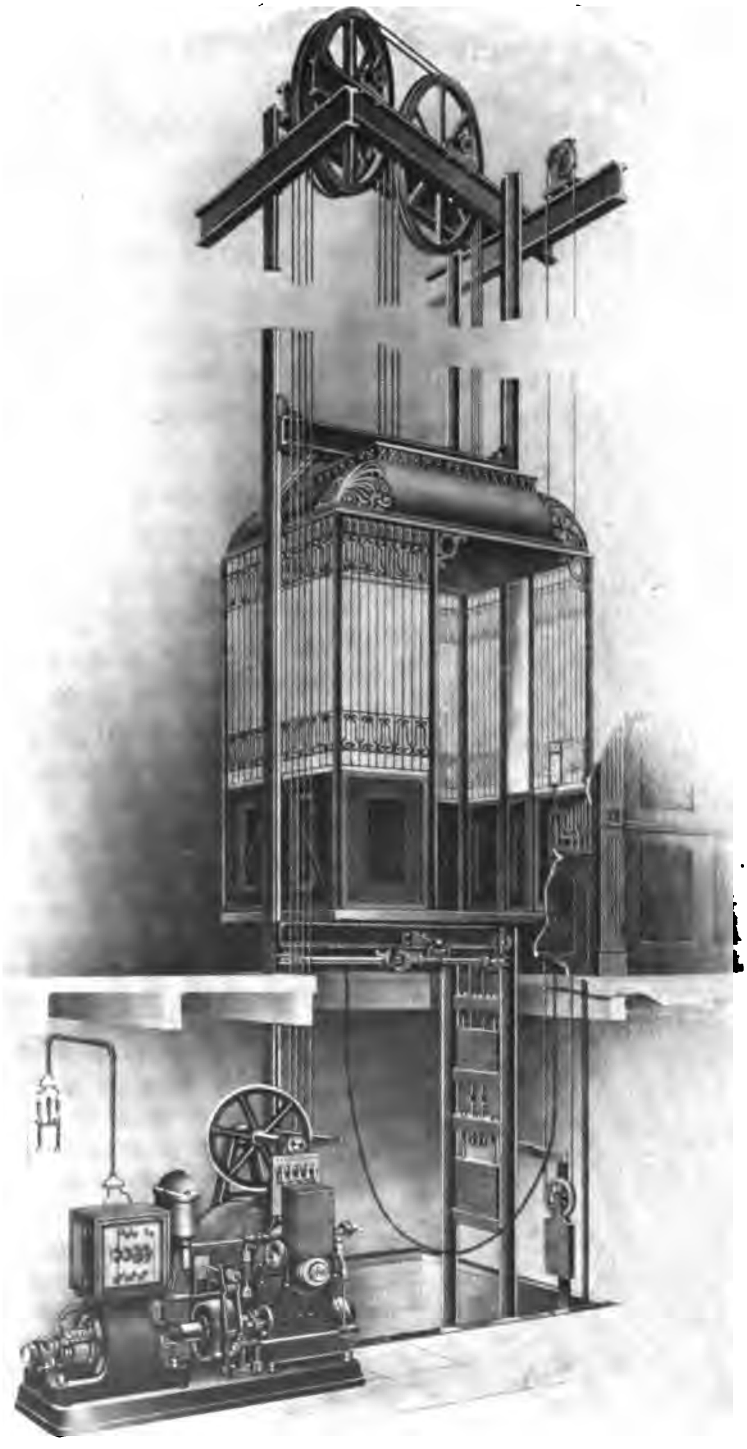
Fig. 22. Modern Light and Power Substation.

able element in a large station in which both these currents are generated, the direct current for general distribution, and the alternating current for transmission to substations. A frequency of 25 cycles is therefore generally accepted as the most desirable for straight transmission; but the alternations are noticeable on incandescent lamps at even 30 cycles, while arc lamps will not burn at all satisfactorily on frequencies of less than 40 cycles. Because of these facts, the alternating distribution, as distinguished from transmission to substations, is effected by 60-cycle current. The 25-cycle transmission current is then converted to current of 60 cycles per second by means of motor generators or straight frequency-changer sets.

In Europe, a compromise frequency of 42 and sometimes 50 cycles is common; and current is transmitted and distributed at this frequency, thus requiring only voltage transformers and no frequency changers. A few 25-cycle systems have been installed in Germany. For converting to direct current, motor generators are used more freely than are rotary converters. European transmission lines of 10,000 volts three-phase are not uncommon.

With the advent of polyphase transmission in connection with lighting and power systems, the old 500-volt power lines are gradually being abandoned, the power load being connected to the 230-volt circuit of the Edison three-wire system, or, if in the outlying districts, to the polyphase 60-cycle lines. Series arcs have already been largely displaced by constant-potential arc lamps. What this new system meant to the neighborhood in which the old stations were located, will be appreciated when one remembers the noise and dirt and smoke of these old stations, and then views Fig. 22, a substation set in the rear of a lot in a fine residence section.

We have seen, then, how the high-voltage polyphase system has been evolved out of, and has unified, the mixed systems which were brought under one head during the era of consolidation. A study of some of the newest installations leads to the thought that perfection of system has almost been reached, and that further progress will be rather along the line of higher efficiency of apparatus at both ends of the system. When the true electrical era has arrived, when houses no longer have need of chimneys and all operations are performed electrically, then new problems will arise. How they will be met, none can now say; but they will be met successfully. Another Edison—many of them, perhaps—will arise; and then our splendid systems of to-day may ultimately be supplanted by one of which the most imaginative dreamer as yet has seen no vision.



WARNER AUTOMATIC PUSH-BUTTON ELEVATOR
No "Elevator Boy" Needed.

ELEVATORS

The elevator as a modern appliance has become a very important factor in business life. Fifty years ago it was comparatively unnecessary, and in the few instances in which it was in use, it was considered more of a luxury than a necessity. The earliest form of elevator was used only for merchandise, and the power employed was derived from a revolving shaft through the medium of leather belts running over pulleys. The introduction of steam, however, as a source of power for its operation, made a change in the speed that could be attained, and enlarged considerably its field of operation. It then began to be used for passengers as well as goods.

EARLY STEAM ELEVATORS

The application of steam for this purpose was made in a modified form, the engine employed being a double cylinder engine with the cranks set at right angles to avoid centering, but the valve motion was the principal feature of difference. Of course, many experiments were tried in the beginning, but what we shall describe here is that form of valve motion which became generally adopted. The distributing valves were of a special type, resembling more than anything one ordinary D-valve within another, and the number of ports in the cylinders were four each; Nos. 1 and 3 being the usual distributing ports carrying steam to each end of the cylinder, and Nos. 2 and 4 being used alternately as steam and exhaust ports. The starting and stopping was done by means of a change valve, which alternately, at the will of the operator, converted one of the latter mentioned ports into a steam supply port and the other into

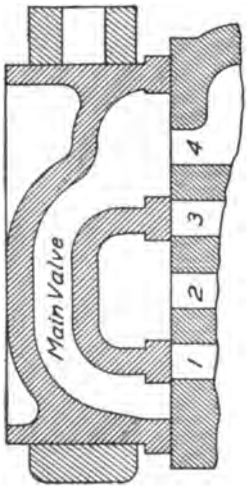


Fig. 1. Distributing Valve.

an exhaust. These valves — one change and two distributing — were all three contained within one steam chest, and the pressure of the steam from the boiler was always on them, holding them to their seats. The change valve, however, was the only one which opened a port directly into the steam chest. The operation of these valves and their arrangement will be readily seen by reference to the accompanying illustration.

It will be seen from the illustration that with this arrangement of valves there could be no lap or lead in the distributing valves on the cylinder faces, because the valves had to act alternately for steam supply and exhaust, and any lap or lead that might be given them for operation in one direction would produce a distorted action when used for running in the reverse direction. The consequence was that the engine of this type was not economical in its use of steam; and while it was a great favorite at the time of its introduction, and for many years afterward (because of a lack of anything better) it has, since the introduction of the

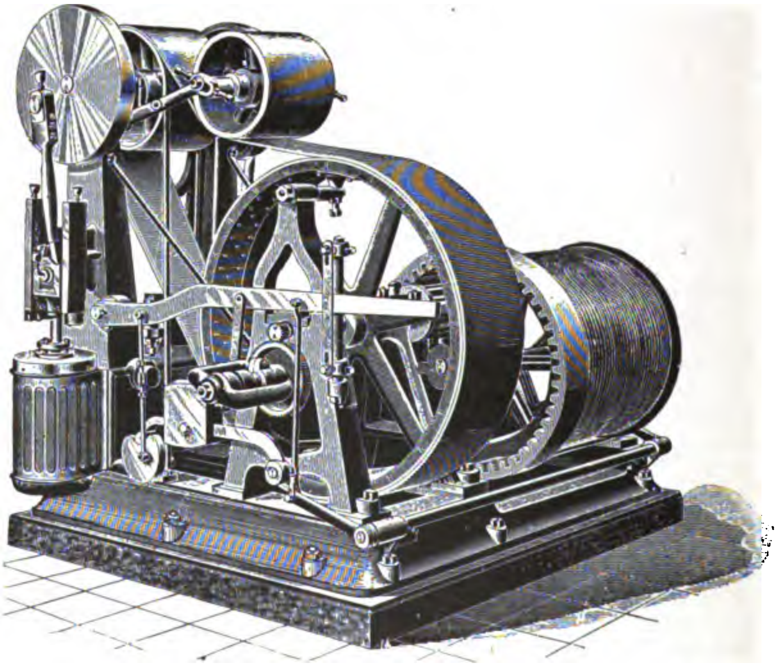


Fig. 2. Spur-Gear Elevator Engine.

hydraulic and modern types of electric elevators, almost gone out of use.

At the time of its introduction it was used entirely in connection with spur gearing, the first types of this engine being made to drive a pulley on the crank shaft which was belted to a larger pulley running in stands on the engine bed, the shaft which this pulley drove having on its end a spur pinion meshing into an internal gear, which was bolted to the end of a hoisting drum or spool which wound up the cable or wire rope, to one end of which the traveling platform or cage was attached. This wire rope passed from the hoisting drum up the hatchway and over grooved wheels or sheaves at the top of hatchway and then down to the cage, and the change valve, by means of which the steam was shut off or turned into the engine to operate it in either direction, was connected to a wire rope of smaller diameter, which led up the hatchway within easy reach of the operator, and the pulling of this rope up or down was sufficient to start the elevator in either direction.

The amount of steam, however, under pressure, required to operate the engine when lowering a load, was so much less than that needed for hoisting, that in order to prevent the engine from racing and lowering at an undue speed, the change valve was always adjusted to give a very small opening into the steam supply when running in this direction, and in addition to that a certain amount of lap had to be given to the valve on the exhaust side, so as to choke the exhaust and thereby retard the descent. There was some danger of overloading of the engine, for in case an overload was placed on the cage, of course an attempt to lift it would fail, but in lowering, especially when the steam was shut off quickly, the pressure of the confined steam in the cylinders would sometimes exceed that in the steam chest, in which case the distributing valves on the cylinders would be lifted from their seats, and where they were fitted to work in a yoke or buckle, at the end of the valve stem, they would remain off the seat, when once lifted therefrom, until replaced. There was nothing then to hold the load but the brake, and to obviate this trouble it was customary in many cases to bolt to the bottom part of the steam chest an angle piece fitting closely at the back of the valve. This piece being stationary, and its vertical side parallel with the cylinder face, the valve worked up and down between it and the valve seat, and it prevented the valve from being raised from its seat.

The brake used on this type of engine was a flexible band of steel, which was lined with hard maple in short sections and fastened to the band by screws. A suitable lever for applying the brake, with a heavy cast-iron weight on the end of the lever and proper adjustments for taking up the wear, completed the outfit. The brake was always applied by means of the weight on the end of the brake lever and was released by means of a heart-shaped cam fastened to a pedestal or stand on the engine bed and operated by the yoke or automatic stop, which, being connected to the operating cable in the hatchway, before described, was always actuated when the hand cable was pulled to the center of its throw.

The pistons of these engines were usually very simple in construction; they consisted of a disc or block of cast iron properly bored and fitted to the piston rod and turned with grooves to receive the piston rings, which were then sprung over the block into their respective grooves. They were made slightly eccentric, being thicker on the side which was left uncut, and were usually turned little larger than the bore of the cylinder. When they were cut, a piece had to be taken out, leaving a space of about $\frac{3}{16}$ inch between the cut ends, and the rings consequently had to be squeezed together or compressed in order to enter the ends of the cylinder, and this caused a constant outward pressure of the piston rings. They were made two in number; in some cases three, and were usually from $\frac{3}{8}$ to $\frac{5}{8}$ inch wide.

Owing to the confined space into which these engines had to be put at times, it became necessary to reduce them somewhat in height in order to get them into low basements when desired. The consequence was that the connecting rods were not always as long as the best practice would dictate, and as a consequence of this, and the constant reversing of the engine, it was frequently found somewhat difficult to make them run quiet. Now, however, with care, this result can generally be attained.

Another cause of hammering in this type of engine was a lack of care on the part of the manufacturer to so proportion the length of bore of cylinder as to allow the outer piston rings to just pass over the end of the bore at the end of each stroke. This length of bore, of course, was determined at the time of counterboring the cylinders, and where the bore was so long that the piston rings did not quite reach the ends of it, they would in time, as the bore of the cylinder enlarged from constant wear, leave a shoulder at each end. Against this shoulder the rings would strike at the end of each stroke, and if the engineer was not posted on this peculiarity, he would probably try for months to get his rods to run perfectly quiet without good results. The only remedy in a case of this kind would be to take out the pistons and file the shoulders, before mentioned, but it would be only temporary. The proper way to get rid of the evil entirely would be to counterbore the cylinders a little more, but it was a job that was attended with considerable difficulty with the engine in place, hence the first method would be found most satisfactory.

The cross heads and guides were similar to those of most engines, whether horizontal or vertical, and differed with the ideas and taste of the maker. Several different arrangements were used; some with plain straight slides, some with V-shaped; but the most popular was that of the bored guides, for cross heads, using a bronze shoe with proper adjustments for wear. These engines would often run as high as 500 r. p. m. at full speed.

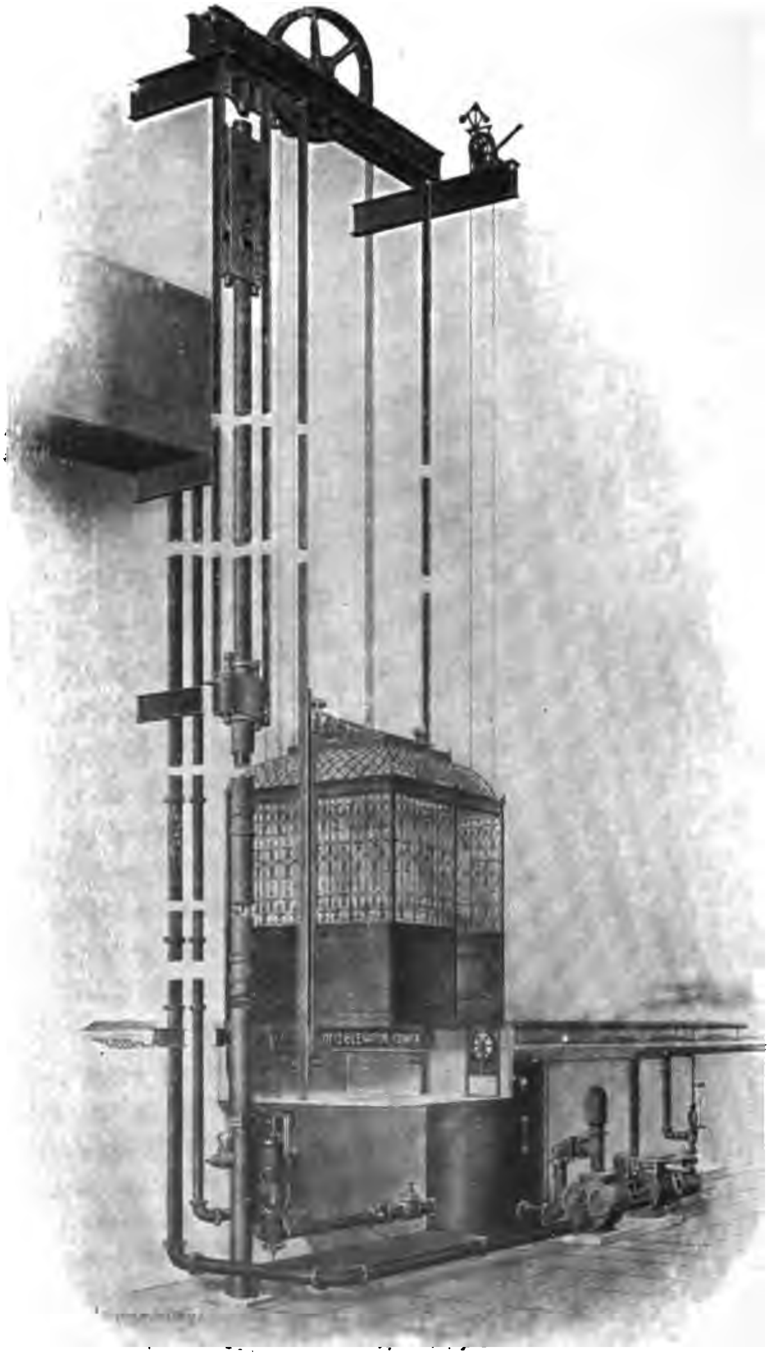
One feature of this engine which frequently caused great annoyance was the running off of the belt which connected the pulley on the crank or engine shaft with the large pulley, before mentioned, running on a shaft in stands on the bed. There would seem at first sight to be no good reason why a belt of this kind should not run well and in line, but frequently carelessness in workmanship was the cause of this, for if the pulleys themselves were of equal diameter at each side, and the shafts were not perfectly aligned with one another, it would cause this trouble; and while the belt might be adjusted to run well in one direction, it would run off the pulley when the engine was reversed, there being a "tightener" for the purpose of taking up the slack of the belt, which could be adjusted so as to cause the belt to run well in one direction. The distance between centers of shafts being short, the belt was necessarily short too, seldom exceeding 19 feet in entire length. and it was always endless, that is, without seam or lacing.

The writer has frequently seen on some of the older types of these engines a pulley that was larger on one side than the other; this also would cause the trouble.

Another defect in this engine was the liability, when the belt had been in use a great while and neglected, for it to become dry and cracked, and if it broke either when lifting or lowering a heavy load, there was a chance of the cage falling, there being nothing to hold it in that case but the brake. To automatically apply the brake and at the same time shut off steam, in case of an accident of this nature, there was attached, to one of the arms carrying the idler, a vertical rod The lower end was attached to the cam operating the brake; the upper part of this rod was hollow and the lower part telescoped into it. A collar and set screw on the lower rod being set in the proper position would receive the end of the upper rod on its face, in case the belt should break or come apart, for the great weight of the idler pulley would cause it to fall, carrying the arm to which the upper part of this rod was attached. This then would throw the brake cam around in the position to apply the brake, and at the same time shut off the steam, thus stopping the engine also.

This pulley, which performed the double office of tightener and as an adjustment for the direction of the belt, was very necessary, because as the belt stretched from constant use, this idler, running on top of it, and being made very heavy for the purpose, would take up the slack of the belt, causing it to have greater contact with the pulleys. The arms, which carried the shaft upon which it ran, were attached to the upper part of the engine frame and extended outwards toward the rear of the engine, and were of such a length as to leave the pulley in the right position upon the belt just between the engine pulley and the larger pulley in the stands on the engine bed. Sometimes, however, a sudden stoppage of the engine would cause this tightener to jump away from the belt and then drop back upon it, and this feature had a tendency to cause the belt to break whenever it became weakened in any part.

To prevent this jumping of the idler, which also had a bad effect on the stopping of the engine, spiral springs were sometimes attached to these arms and carried down to a convenient point below where they were attached either to the bed of the engine, or to



PULLING PLUNGER HYDRAULIC PASSENGER ELEVATOR.

the wrought-iron braces which stayed the upright frame to the bed. Turn buckles were provided to give the springs proper tension, and this remedied the difficulty just related.

When these engines were at rest the steam chest was always full of steam and ready at any moment to start upon the change valve being opened in the proper direction. As this steam chest radiated considerable heat, there was always more or less water of condensation in it. A drain pipe was run from the bottom of the steam chest to a steam trap, which was set considerably below the level of the bottom of steam chest, and the water escaped to this steam trap.

The automatic stop was a screw provided with a traveling nut and adjustable set collars. This screw was a sleeve which usually ran upon a long stud bolted to one of the stands in which the larger pulley shaft ran, and it was geared to the pulley shaft by means of a spur gear and pinion, which were so proportioned as to give this automatic screw about the same speed as the drum shaft. The traveling nut was so arranged that at either end of the run it would

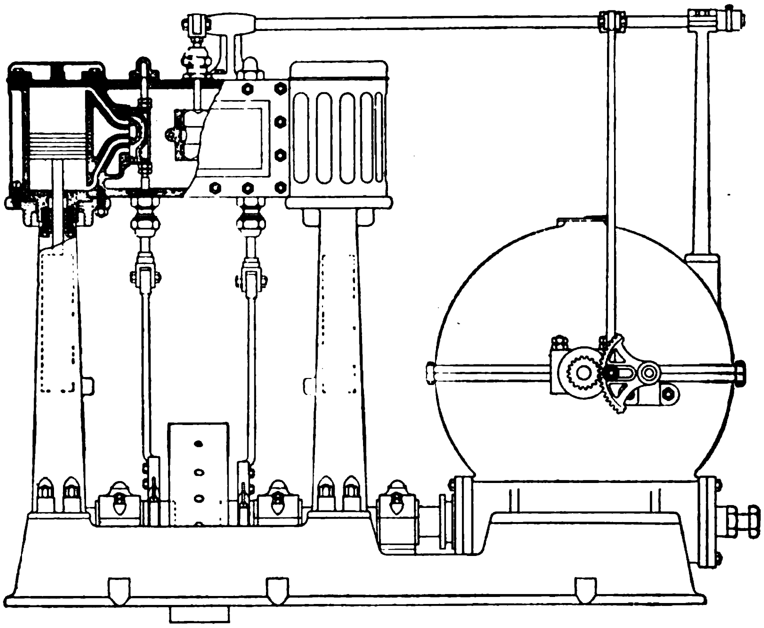


Fig. 3. Elevator Engine with Worm Gear.

come in contact with the set collars, which had to be set just to the right position to gear with this traveling nut. They each had a tooth which interlocked when the traveling nut and collar were brought together. By this means, the traveling nut was made to revolve, and as it turned, the automatic yoke, which was connected to the starting lever by means of a link connection, operated the change valve and applied the brake at the same time, thereby stopping the engine at the limit of its run. This end was also attained by means of stop buttons on the operating cable, which were made so as to clamp the cable wherever they were placed and tightened up, and a striker or arm attached to the cage so as to slide up and down on the operating cable freely. Whenever the striker came in contact with one of these stop buttons it pulled the cable the same as the attendant would, and thereby also shut off steam and applied the brake. The operations were identical in each case, except in the method of arriving at results. A pressure of from 60 to 90 pounds of steam was usually carried at the boiler.

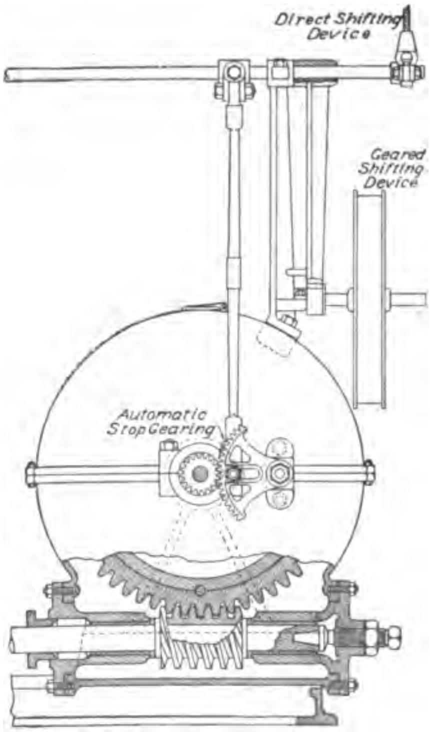


Fig. 4. Worm Gear in Housing.

The lubrication of the wrist and cross head pins, eccentric straps, etc., was usually supplied by means of compression grease cups. This method was adopted on the score of economy and cleanliness; the valves were lubricated by means of a self-feeding cylinder lubricator.

The chief difficulty with the spur gear type of engine was that of low pressure and overloading. It sometimes happened that when there was no steam on the engine at all, the car being left at one of the upper stories, an ignorant attendant would put load on the car and pull the operating cable. The brake being released, the load would run the engine backwards and run to the bottom violently. Of course, when these engines and their peculiarities became well known, accidents of this kind were less frequent, and taking it altogether, the service rendered by these engines was invaluable. Being the most rapid up to the time of their introduction and for a long time afterward, they were a favorite for many years, the principal objection to them being the cost of operation in comparison with other methods introduced later.

Later on a modification of this engine was used for passenger service. The changes consisted of the use of a worm gear in place of the spur gearing just described, and owing to the location of the worm shaft it necessitated the use of an engine with the cylinders inverted, and placed at the top of the engine instead of below as in the original form. This arrangement has some advantages for passenger work, as the liability to run down, which always exists with a hoisting machine where spur gearing is used, was eliminated. It was also considered safer and more desirable for passenger use on account of its smoother action and the fact that the breakage of one or two teeth in the gear would not cause the platform to descend rapidly. The other characteristics of the engine were not changed.

WATER BALANCE ELEVATOR

Contemporary with this engine, which attained its greatest popularity during the 70's, there was introduced a form of hydraulic elevator which at one time bid fair to be a successful rival of the steam engine. It was called the water balance elevator. It consisted of the usual cage or cab in which the passengers rode, the cables necessary for hoisting which passed up the top of the hatchway in the usual manner and over sheaves, thence down into a large metal tube or well hole, and attached to the other end of these cables was a large bucket that nearly filled the well hole just mentioned. At the top of the well hole and above the highest point to which the bucket traveled, there was a tank containing water supplied by means of a steam pump. At the bottom of the bucket was a discharge valve, which as well as the valve at the bottom of the tank just mentioned, were operated by means of pedals located in the cab.

The operator by pressing the appropriate pedal with his foot would discharge water into the bucket from the tank above. When sufficient water had accumulated in the bucket to more than balance the weight of the cage and its occupants, the elevator would begin to move, the water in the bucket forming a counterbalance weight and virtually dropping down the well hole dragging the cage upwards, and vice versa, when the water was allowed to discharge itself from the bucket it would become lighter than the cage and the cage would drop. This water having been discharged into a tank at the bottom of the well hole, would be pumped again into the overhead tank.

The speed of this elevator was unlimited, and was governed entirely by the use of a powerful brake gripping the slides or rails on which the cage traveled. This brake was arranged by means of very strong springs which always held the brake on, and had to be released and held off by hand to obtain any movement of the cab when the conditions for motion were right; and in letting go of the brake, it applied itself with sufficient power to stop the elevator.

This form of elevator was found to be very expensive, both to install and operate, and moreover, was dangerous in the hands of unskilled men, and it soon went out of favor upon the introduction of the horizontal hydraulic elevator. The latter was originally the invention of William Armstrong, a man prominent among mechanical engineers in Great Britain.

HORIZONTAL HYDRAULIC ELEVATORS

The first elevator of this type was used for the purpose of hoisting stones from a quarry in Yorkshire, but its utility as an elevator for merchandise was soon recognized and it began to be used extensively for this purpose in that country, and it was along in the early '70's that it was first introduced into the United States. The earlier machines of this type were usually operated by water pressure obtained from the city mains. The machine consisted of a cast iron cylinder, the bore and length of which varied according to surrounding conditions, being chiefly governed by the water

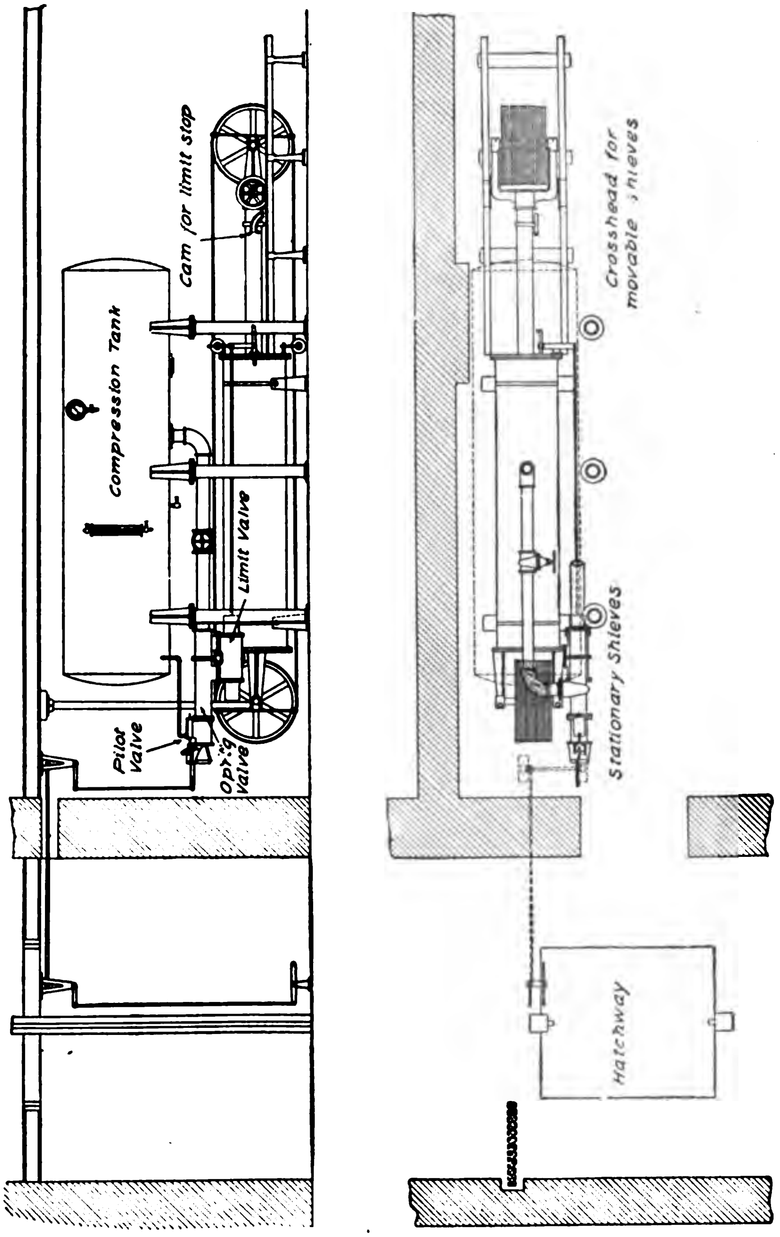


Fig. 5. Plan and Elevation of Horizontal Hydraulic Elevator.

pressure available and the height of the building in which it was used. A piston, fitting closely in this cylinder, was made water tight by means of suitable packing. There was a piston rod and cross head which carried a set of traveling sheaves, and a set of fixed sheaves. The cross head traveled on a track provided for the purpose, which acted both as a support and guide for same. The cable which hoisted and lowered the cage, passed up the hatchway in the usual manner over sheaves at the top of same, thence down to one of the fixed sheaves below on the end of the machine. From there it passed successively along under the machine, around one of the movable sheaves on the cross head, back to one of the fixed sheaves at end of machine and so on three or four times, and the other end was finally made fast to the hydraulic engine. This arrangement of rope and sheaves was exactly like a block and tackle, the cage being attached to the loose or running end of the rope. Now when water pressure was applied to the piston, it would pull these sheaves apart, causing the end of the cable in the hatchway to raise, with the cage attached, at a speed much faster than that at which the piston traveled, the difference in speed being governed by the number of sheaves collectively on the machine. For instance, if the cross head had four movable sheaves traveling with it, and at the fixed end of the machine there were four sheaves, the ratio or difference between the speed of cage and that of the piston would be 8:1; in other words, the cage would travel eight times as fast as the piston, and eight times as far. The ratios more generally used are from 4:1 to 10:1, depending on the speed required and the load to be lifted. With this arrangement when

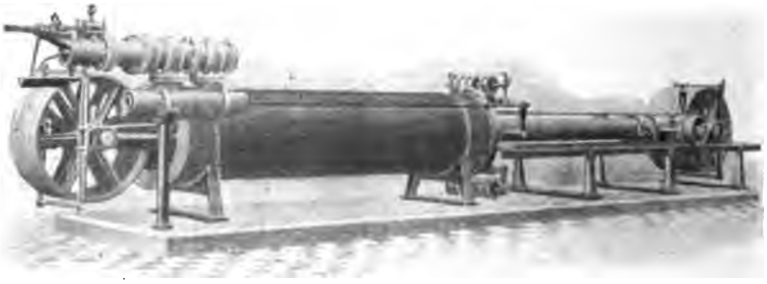


Fig. 6. Horizontal Hydraulic Elevator.

connected to the city mains, the water, after being used, was wasted or allowed to run to the sewer. Later on, the introduction of the roof tank permitted water to be used over and over again, the same as in the water balance elevator. A still greater advantage was gained by the introduction of what was called the pressure tank. This was a modification of the accumulator so much used in Europe in connection with hydraulic presses, and consisted of a reservoir that was fitted with a plunger of large area, which worked vertically through a tight stuffing box, and having on its end an enormous weight or load of cast iron. Water being pumped into this accumulator, raised the plunger with its load, and when draft was made upon it, it would force this water out into the cylinder of the hydraulic ram with a pressure equivalent to that of the load carried.

The pressure tank was similar in arrangement, except that the compression of air above the water gave the pressure required. A cylindrical tank properly braced and stayed was used, with inlet and outlet pipes and water glass to show the height of water in the tank, and a pressure gauge. Air would be pumped into the tank up to a moderate pressure, afterwards water would be pumped in, and this water further compressing the air, would produce an ultimate pressure of anywhere from 100 to 150 pounds per square inch. The inlet and outlet pipes for the water were directly at the bottom of the tank to prevent the escape of any of the air, and when water was drawn off from this tank in the cylinder of the hydraulic engine, the drop in pressure would not be more than a very few pounds, owing to the expansibility of the air above the water, about one-third of the total contents of the tank being air under pressure.

This arrangement enabled higher speeds than was admissible with the street main service, the street pressure of many cities being low; in fact those having a high pressure—anything from 60 to 100 pounds—being rare. Moreover this arrangement had other features which were desirable, the absence of water hammer in the pipes being one, the using of the same water over and over being another, and the ability to have the most useful pressure being a third. With the higher pressure, cylinders of a smaller diameter could be used, and consequently a less amount of water also.

The operation of the hydraulic elevator was by means of a two-way valve, the most improved type of which consisted of a cast iron cylinder with a brass lining, which was perforated opposite the openings or branch pipes in the cast iron body. Inside this brass lining was a plunger with leather cup packings held in position by discs of brass, which were so arranged as to cut off the supply of water gradually so as to produce an even and gentle stop. Where the supply was taken from the city main an additional precaution was taken of using an air chamber on the supply pipe near the operating valve. The office of this was to prevent violent shocks in the pipe from the sudden stoppage of the flow of water through the same, caused by shutting the operating valve quickly. The water in the main, when the valve was closed, would continue its onward course up into the air chamber, the air in which being compressed, would act similarly to a spring, gradually retarding the flow of the water and restoring its equilibrium, but in the case of the compression tank it acted of itself as a huge air chamber.

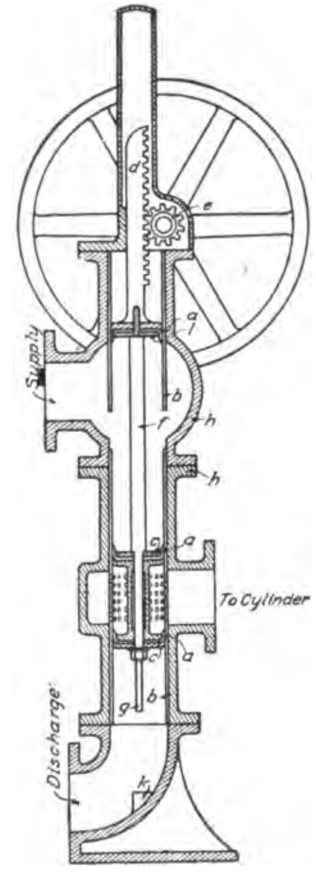


Fig. 7. Two-Way Operating Valve.

a, Leather packing cups; *b*, Brass lining of valve, *c*, Brass plates supporting leather cups; *d*, Brass rack in which pinion works to lift and depress the plunger; *e*, Steel pinion; *f*, Steel stem to which all the parts of the plunger are attached; *g*, Extended end of steel plunger which serves as a stop to downward stroke of plunger by striking on *k*; *h*, Cast iron body of valve.

Depressing the plunger allows the water to flow from supply to cylinder. Raising plunger allows water to discharge from cylinder.

With the higher pressure obtained by use of the tank, greater speeds could be attained, frequently as high as 300 or 400 feet per minute, while with the street main system it rarely exceeded 150 feet per minute, and frequently was as low as 50. The compression and roof tanks were usually kept supplied with water by means of powerful steam pumps, the change of level of water in the tanks being made to automatically turn on steam or shut it off. These pumps, therefore, were not obliged to run constantly, but only when the supply of water in the tanks became somewhat depleted, the pumps running simply long enough to supply the deficiency.

When the higher speeds were found desirable and attained, some better means of operating the elevators than the hand cable became a necessity, and the invention of the lever operating device followed. With it came the pilot valve. This was a small auxiliary valve attached to the main operating valve which obtained its power from the pressure tank. The operator in the cab moving his lever, would open the small pilot valve, which in turn admitted water to a piston on the stem of the main operating valve, the pressure of the water moving this piston in either direction as desired, and with it the main plunger of the operating valve. The pilot valve itself and its connection with the plunger of the main operating valve is so constructed that a partial movement of the operating lever would produce a partial opening of the pilot valve, and in turn, a partial opening of the main valve, if so desired. The full opening and closing were obtained by the full movement of the operating lever.

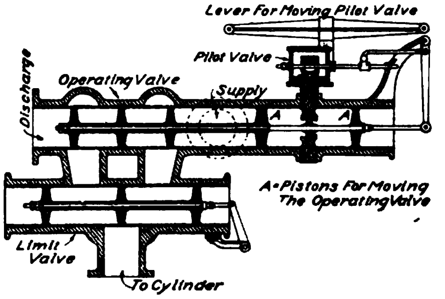

Lever For Moving Pilot Valve
Pilot Valve
Discharge
Operating Valve
Supply
A
A
A-Pistons For Moving The Operating Valve
Limit Valve
To Cylinder

Fig. 8. Auxiliary and Operating Valves.

VERTICAL HYDRAULIC ELEVATORS

The horizontal hydraulic elevator had not been in use very long, when Mr. C. W. Baldwin, of New York, conceived the idea of using a vertical cylinder. This was not entirely new, as they had been used in Europe, but not exactly in the manner in which he proposed to use his. The advantage of his form of hydraulic elevator was that it took up less room in the building, because it could be set up in the same hatchway with the traveling cage, in one corner of the well hole, and for the sake of economy in space it was usually made with a ratio of from 2:1 to 4:1, instead of from 6:1 to 10:1 as with the horizontal hydraulic. The consequence was that the cylinders were necessarily quite long, though smaller in diameter than the horizontal machine. They differed also from the horizontal in the fact that they did not use any guide ways for the cross head.

The cylinder being set vertical and a fixed sheave directly above it, the end of the hoist cables were made fast to a beam overhead and led thence down to the cross head and around the sheave in same, and up again over the fixed sheave before mentioned, thence over the sheave in hatchway directly above cage. This gave the machine a speed ratio of 2 to 1, and the piston would travel just half the distance of the cage, but it was found that a great loss of pressure occurred at the beginning of the travel, owing to the top of the cylinder being so high above the level of supply. To equalize this, the discharged water was returned through a circulating pipe to the bottom of the piston, instead of discharging it into the surge tank or sewer immediately after it was used. By this means the weight of the water beneath the piston was used to equalize the pressure, but as this water beneath the piston was held there by atmospheric pressure until discharged, it was found that the length of the vertical cylinder could not be more than 33 feet at sea level, or its equivalent in other places. This limited the length of vertical cylinder that could be used, so that the ratio of this type of machine was governed somewhat by this.

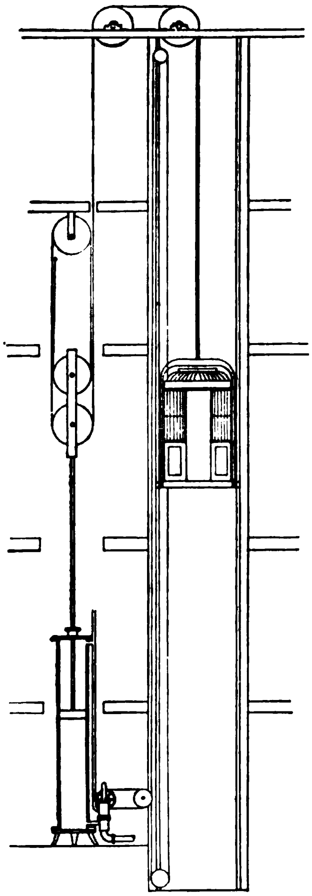


Fig. 9. Vertical Hydraulic Elevator.

But with all these machines, both horizontal and vertical, where the pressure was comparatively low, a great loss of power was caused by the friction of the piston in the cylinder, and the flow of the water through the pipes, as well as the difference in weight of the cables, depending on whether they were hanging in the hatchway on the side of the car or on that of the machine. These cables, which were usually four in number, and sometimes more (and generally of about $\frac{5}{8}$ inch diameter, weighing about $\frac{3}{4}$ of a pound to the foot), would, when the car or cage was at the top of the hatchway all hang down towards the machine, and in the case of a building say 100 feet high would amount to over 400 pounds. Now while as a measure of economy, it was desirable to counterbalance the weight of the cage, it could not be done very closely with this difference in the weight of the cables on one side or the other, according as the cage was at the lower or upper landing. Hence, some means of counteracting this was found desirable, and it was done by hanging chains in the hatchway, one end of them being attached to the wall of the hatchway about half way up the run or travel of the cage, their other ends being attached to the bottom of the cage. It will readily be seen that when the platform or cage was down at the bottom of the run, and consequently the cables on the car side hanging down in the hatchway and equalizing the weight of those on the other side, the chains would be hanging on the wall, but that when the cage was at the top of the hatchway and the weight of the cables preponderating on the other side, these chains would be hanging on the bottom of the cage, thus offsetting the weight of the cables. By this means closer counterpoising could be obtained, and the desirability of this method of counterpoising, in after years, when much taller buildings came into existence, may very readily be seen. In fact, it became quite indispensable in the case of buildings of 17 or 18 stories.

Later on, the introduction of the electric elevator and the claim made for its economy of operation caused elevator builders to look for more economical methods of operating the hydraulic elevators. One of the chief drawbacks to economy in the hydraulic elevator was the fact that the same amount of water had to be used per trip regardless of the load, and the introducers of the electric elevators made the claim that an amount of current proportional to the load carried was all that was used.

The introduction of the high pressure water system in the city of London had attracted considerable attention in engineering circles, and the use of elevators in connection therewith had shown that a greater economy was possible with a higher pressure, owing to reduced area of cylinder, there being less friction and smaller consumption of water. The system of high pressures was introduced here, but it has not realized all that was expected of it. The enormous expense connected with the installation and maintenance are the chief drawbacks, but during the time that was devoted to experimenting with the high pressure systems, one or two types of elevators were evolved that gave considerable satisfaction, one of these being that of using a vertical cylinder with a ram, the weight of which was sufficient to lift the cage with its load. The hoisting of the load, therefore, was done by discharging the water from the cylinder, and when the platform or cage was to be lowered it was accomplished by turning the water pressure against the end of the ram and lifting it. This ram was geared in the usual manner by means of a cross head and sheaves having a ratio of anywhere from 2:1 to 6:1.

Other schemes were devised for economy, one of which was to have two or more tanks at varying pressures, one tank having say 100 pounds pressure, a second 150, and using one or the other according to the load to be lifted, an automatic operating valve being used in connection therewith.

Another form of hydraulic elevator, which has always been very popular in Europe, was the plunger machine or ram. This consisted of a hollow plunger, which passed through a stuffing box in the top of the cylinder which was let down into the ground, the depth of same being the length of run from lower to upper landings, the platform or cage being set on top of this ram. When water was let into the cylinder the pressure of same against the bottom end of the ram forced it up out of the cylinder, and the cage with it, to the top of the building, the lowering being done by allowing the water to afterwards escape. The form of valve and its operation was the same in this case as in that of the other types of hydraulic elevators.

This style, of elevator, however, from the point of economy had one objectionable feature that was peculiar to itself, and which was more noticeable in the higher runs or upper stories of buildings. The plunger being hollow, to insure lightness, had a certain amount of buoyancy when wholly immersed, but when run partially or entirely out of the cylinder, this buoyancy necessarily decreased, and consequently the lifting power of the elevator became less and less as it reached the upper stories of the building. It consequently could not be counterbalanced very closely, because if that were done the plunger, in descending to the lower story, would come to a point where it would stop of itself because of its inability to displace the water in the cylinder. This was a matter that entered largely into the calculation of the area of plunger when arranging the proportions of cylinder and plunger, in relation to the pressure of water to be used.

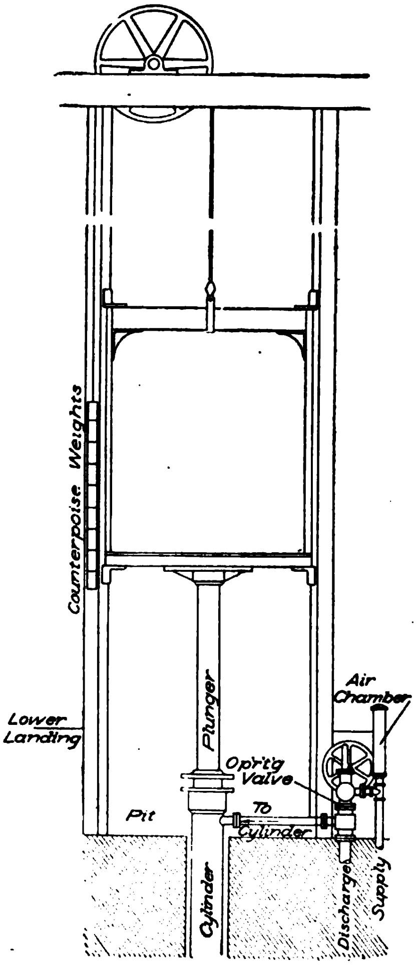


Fig. 10. Plunger Elevator.

The earlier elevators of this type were usually made with a cast-iron plunger, which as before stated, was hollow, and, owing to the brittleness of cast iron, had to be re-enforced by running a heavy wrought iron rod up through the middle of the plunger, the lower end passing through the bottom end of the plunger, the upper end being made fast to the floor of the cage. Without this the sudden opening of the operating valve would allow the escape of water from the cylinder for descent, and when the cage was in the upper story it was liable to cause the plunger to break off. Such an accident as this occurred some years ago in Paris, causing the loss of one or more lives.

In the case just mentioned, the wrought iron rod in the center of the plunger was absent, its absence being a fault in the design of the machine. To-day, however, with the introduction of Bessemer steel tubing, the necessity for the center rod does not exist, the ends of the tubes being threaded internally, and a male coupling being used inside the pipe. The joints in the cast iron plunger were made by boring out the ends of the sections of the plungers and inserting a thimble nicely fitted, which entered each end of the adjacent sections to a distance of 3 or 4 inches, the ends of the sections of the plunger themselves being faced or squared off perfectly in the lathe, and the whole being put together with a hydraulic cement composed of litharge and red lead mixed with boiled linseed oil, or Japan varnish. These machines are very much in vogue to-day for short runs, and despite their lack of economy in operation, which must necessarily exist owing to the conditions described, a company has within the past few years been formed for the exclusive manufacture of this style of elevator.

PACKING AND LUBRICATION

Of course, in the manufacture of all the styles of hydraulic elevators here described, a very important feature is the condition of the bore of the cylinders and the external diameters of the plungers. It is absolutely essential that both cylinders and plungers shall be parallel and smooth, any inequalities or inaccuracy causing a waste of the water used in operating them, and one of the most essential features in their care is the proper, and even, setting up of the packing, both in the glands of the plunger machine and in the piston of the cylinder machine.

Many forms of packing have been devised, the earliest being the leather cup, which is almost as old as the hydraulic press, in which latter it proved to be the most successful packing ever devised. In a hydraulic press, the ram or plunger travels a very short distance and very slowly, and under exceeding great pressure, but with the lower pressures used in hydraulic elevators, and with the greater rapidity and distance of travel of the piston, this style of packing was not found to be as long lived as could be desired. Hence, various other means were devised to overcome the defects found to exist in the leather cup. One of the best was that of using a leather cup exactly as the original, but smaller than the diameter of the cylinder by an inch or inch and a quarter, and to fill up the space between the leather cup and the bore of cylinder, rings of ordinary square pump piston packing, made of alternate layers of rubber and canvas, were used. These were held in place by means of a follower ring, and through the web of the piston leading directly behind the leather cup, small holes were drilled which permitted the water in the cylinder under pressure to obtain access behind the leather. This pressure forced the leather outwards against the aforesaid rings of piston packing, pressing them against the bore of the cylinder, and allowing the passage of the piston in a water tight condition.

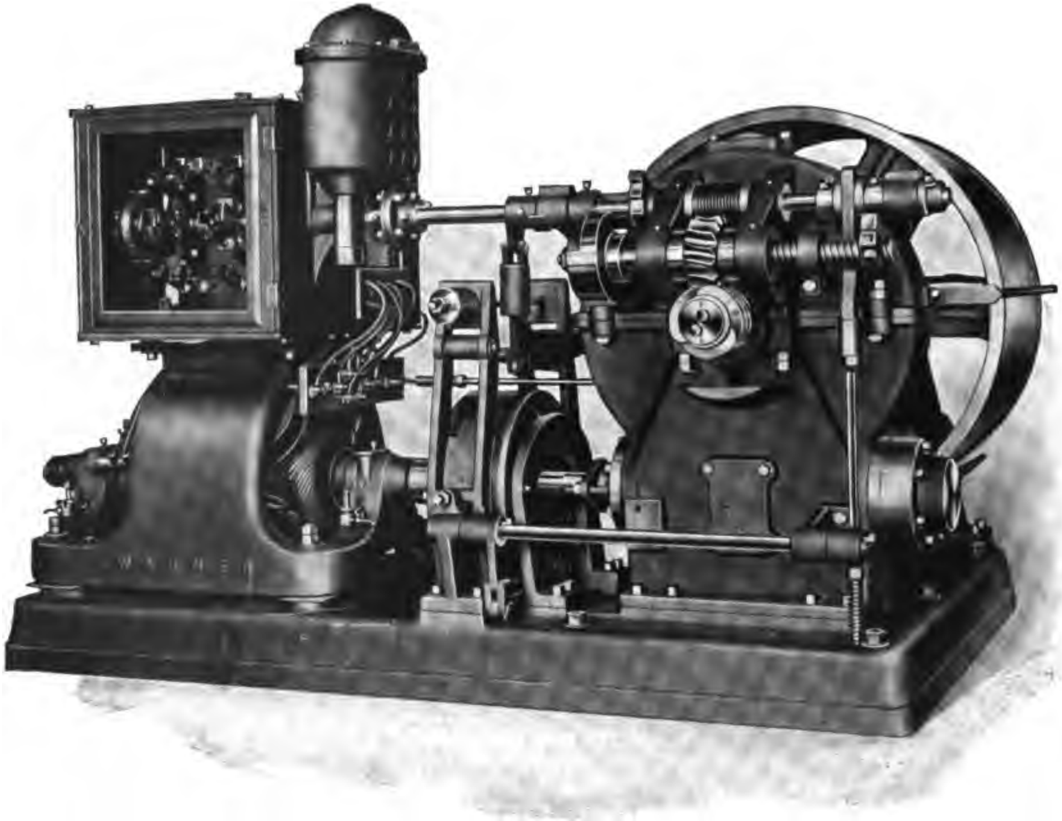
This form of packing was used very largely in the vertical hydraulics, described above, and introduced by Mr. Baldwin, but this form of elevator had one great disadvantage over the horizontal type of machine, in that both ends of the cylinder were closed, and these conditions did not permit of proper lubrication. Hence, after machines of this type had run a few years the cylinders became badly scored or grooved, and there was a great leakage of water past the piston, and the only remedy was the reboring of the cylinders. In many cases, especially where elevators of this type had been installed where the water pressure was low, the cylinders had been designed with such thin metal in the walls that they would not admit of reboring.. In some cases, engineers had tried to introduce a lubricant in the water used to operate the elevators, but with no very marked success.

With the horizontal machines, however, one end of the cylinders being open, lubrication became an easier problem to solve. In these machines, owing to the greater diameter of cylinder, the leather cup and piston packing was not so readily applied and in lieu thereof, several forms of packing were adopted by different makers, each having his own particular choice. In some cases, plaited hemp was used. Others used the square piston packing made of rubber and canvas before described. Still others used rubber cord; some used it in the square strips and others round with alternate layers of square piston packing, and each of these had its own particular merits and advocates.

The piston had to be made with an annular space for the reception of this packing, so shaped that the pressure of the necessary follower ring, which was essential to the tightening up of the packing, caused it to be forced outwards against the internal sides of the cylinder. This follower ring was made with a roomy groove in that part of it which extended outside beyond the packing, and from this groove extended a pipe leading out beyond the open mouth of the cylinder to the cross head where a large compression grease cup was fastened and kept filled with grease. The tightening of a screw in this grease cup forced the grease through the pipe into the groove in the follower, thereby keeping the cylinder constantly lubricated at every stroke, and to prevent its escape through the open end of cylinder and consequent waste, a "wiper" or single ring of packing was used with an auxiliary follower ring to tighten it up as required.

There is a peculiarity about the lubrication of the cylinders and plungers of hydraulic elevators not generally known to the persons in charge of these machines, which is that nothing but purely animal oil or grease will give perfect lubrication.

Since the introduction of oils and greases that were partially or wholly composed of products of petroleum, their cheapness and adaptability to revolving shafts and bearings has made them a general favorite, but however well adapted they were for lubrication of this nature, they were wholly unfit where water came in contact with the surface, and that is why they were not suited for hydraulic elevators. Each time the cylinder was filled with water, or when, in the case of the plunger elevators, the plunger became immersed in the cylinder, grease or oil that had been applied during the stroke would float away in the water, leaving the bore of the cylinder or external surface of the plunger entirely bare. To obviate this, it was necessary to use a purely animal oil or grease, which, being a better resistant of water, would remain on the metallic surface for several strokes of the piston or plunger, as the



ELECTRIC PASSENGER OR FREIGHT ELEVATOR ENGINE WITH FULL ELECTRIC CONTROL
Warner Elevator Mfg. Co., Cincinnati, Ohio.

case might be, and consequently was more economical and more satisfactory.

LIMIT VALVES

For limiting the travel of the cage to the upper and lower landings, in other words, to cause the water to be automatically shut off at these points independently of the efforts of the operator, the earlier hydraulic elevators depended entirely on button stops on the operating cable, working in conjunction with a striking arm on the cage.

In all elevators it is the custom, in putting on the operating cable, to arrange it in such a way that pulling down on the standing part of the cable which is used by the operator causes a motion of the elevator in an opposite direction, and vice versa. For instance, were the operator to pull the cable down, the car would rise. Now at a proper place on this cable is fastened a sort of clamp, being made in halves for the greater convenience in putting it on, and the two halves being fastened together with bolts. When put in place on the cable and clamped tightly there, it is immovable except with the cable. An arm of wrought iron is fastened to some convenient part of the cage sufficiently high to be out of the way of the operator, and this arm is formed at one end into a ring which slips freely over the operating cable as the car travels, and strikes the button just described, on arrival at either end of the run, moving the cable exactly as the operator would do it to the central or stop position.

This arrangement worked very nicely and filled all requirements as long as the operating cable was in good condition, but it was found in course of time that, as the operating cable wore or its condition deteriorated from any cause (the principal one being dampness in the pit at lower landing), it was liable to break, and this always occurred when it was least expected, the result being disastrous in every instance. In some cases the piston would come out at the end of the cylinder, allowing the water of the cylinder to escape, causing serious damage, for it would continue to flow through the supply pipe, and at the same time the cage would be run violently into the sheaves at the top of the hatchway, often breaking them and causing other serious damage, and in the case of the plunger elevators, the plunger would come out of the cylinder, allowing the water to escape in like manner.

To prevent this, various expedients were devised, among them being the limit valve. This was an auxiliary valve placed between the operating valve and the cylinder, and was so arranged in the case of the horizontal hydraulic elevator that cams attached to the piston rod at either end—one near the cross head and another near the piston—would engage an arm on a rock shaft, moving the arm so as to cause it to close the limit valve, and thereby prevent the ingress or egress of water to or from the cylinder according as the cage was at the upper or lower limit of its run. The earlier forms of these valves were made single acting, that is to say, they simply closed the pipe between the operating valve and cylinder, and they were so arranged that they did not entirely close it unless the car went a few inches beyond the landing in either direction. When this occurred, the valve had to be opened by hand in order to give the cage headway in the opposite direction, and this was found to be a decided disadvantage.

Then another form of valve was devised of the two-way type, taking water through one passage from the operating valve for hoisting, and discharging it through another from the cylinder through the operating valve also, thus giving the operating valve control of the water at all points, excepting the upper and lower limits of the run. With this arrangement it was possible to run down or up to the extreme limit, allowing the limit valves to take care of the stops at either end, because in this case when the limit valve shut off the supply of water for hoisting at the upper landing, it left the opening for lowering still open and vice versa.

This form of limit valve proved all that was required of it, but even *it* was liable to derangement, so to overcome these difficulties and to make it simply impossible for the elevator to run beyond its limit, more care was taken with having the cylinders of the exact length required for the run, plus the length of the piston, and across the open end of the cylinder and spanning the piston rod, which was allowed to pass freely through it, was a very heavy bar of cast iron, which projected some inches beyond the outer diameter of the cylinder. Similar projections were made on the cylinder head on each side to correspond with the ends of the bar, just described, and running along longitudinally between them were very heavy rods of wrought iron or Bessemer steel threaded at each end. The ends of these rods passed through holes in the lugs cast on the cylinder head and through the ends of this bar, and nuts on the ends of the rods bound the bar and cylinder head together. A rubber bumper was put around the piston rod, clamped there firmly, and set partially in a recess made in the hub of the piston, and upon the arrival of the piston at the end of the run this rubber bumper would come up hard against the heavy bar of cast iron, which being made amply strong for the service it was to perform, prevented the travel of the piston any farther, and in like manner the piston came against the cylinder head of the lower limit of travel, there being a similar bumper of rubber fastened in the recess in the hub of piston on that side. Of course, these cylinder heads had to be strongly re-enforced to withstand the strain, and this was found to answer all requirements, for it would always operate, regardless of whether the limit valve or buttons of the operating cable gave out or not.

In the case of the vertical hydraulics, which were known as the standard elevator, an appliance of this kind was not so easily put on, in fact none was ever devised that acted successfully. The only places they could be used was at the upper end of the run and at the lower end, between the cylinder and operating valve, and this had the disadvantage previously described as existing with the earliest form of limit valve on the horizontal machine. If the valve in the circulating pipe was closed it prevented the elevator from running in either direction; hence, it had to be set so that it would not close entirely, and this very fact impaired its usefulness and effectiveness. In the case of the vertical plunger, however, it was very easily arranged, the cylinder being made so that when the plunger got a little below its lower limit of travel it was made to rest upon the bottom head of the cylinder, and fastened around its lower end was a ring which, when it reached its upper limit of travel, would come in contact with the bottom end of the stuffing box, thereby preventing its ever coming entirely out.

ELECTRIC ELEVATORS

The most popular form of elevator in use to-day is that operated by electricity, and the general arrangement of machines now in use is that of a worm and gear wheel actuated by an electric motor, the gear wheel being attached to a winding drum or spool, the whole machine, of course, being bolted to an appropriate bed plate, and the worm shaft fitted with the proper form of braking apparatus for use in stopping.

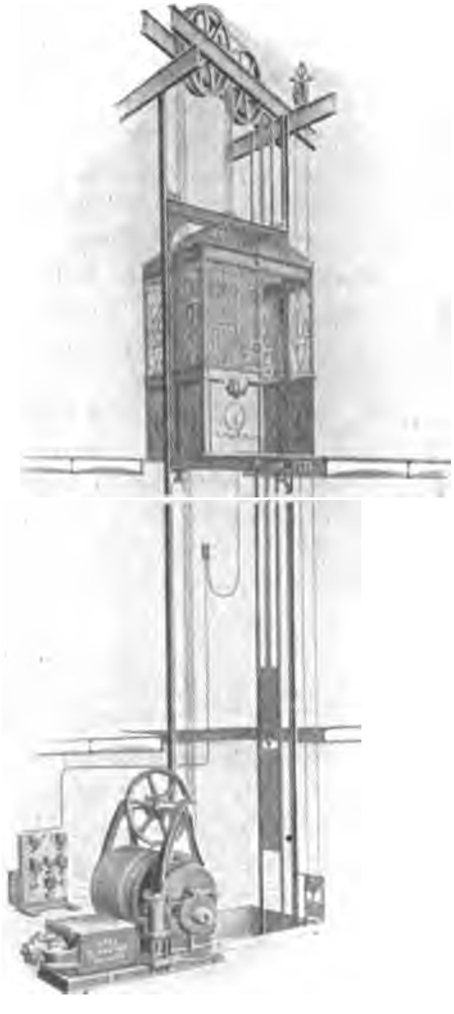
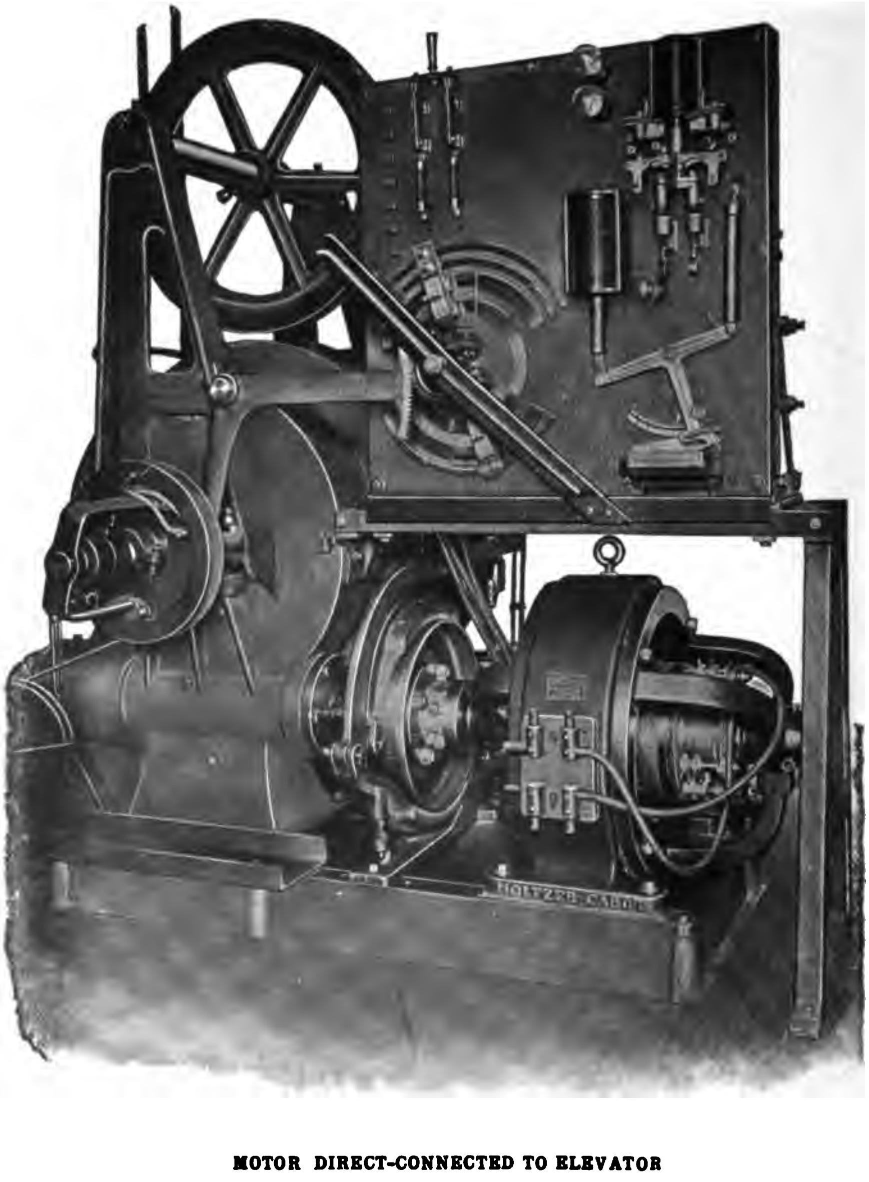


Fig. 11. Electric Elevator.

The motor used for operating an elevator has to differ somewhat from one used in driving ordinary machinery, in that it has to start up from a state of rest with the load on it, and it is a well-known fact that ordinary shunt-wound motors are very weak at starting, hence a modification became necessary. This was discovered very early in the introduction of the electric elevator.

To overcome this difficulty a very strong series field winding is used, and this is usually arranged in two or three sections, and it should furnish fully 30 or 40 per cent of the field excitation. The shunt winding is made proportional to the entire strength of the motor, and when the motor is started, both series and shunt field windings are actuated, and as fast as the motor picks up



MOTOR DIRECT-CONNECTED TO ELEVATOR
Holtzer-Cabot Electric Company.

sufficient speed, one section after another of the series winding is cut out, leaving the motor entirely on the shunt winding when it has attained normal speed. By this means a regular speed under any load is obtained, the series winding being used simply to give the necessary torque for starting.

The reason the series winding is cut out when the motor attains normal speed is that if left in action the speed of the motor would vary with the load, and this would be more noticeable during a descent of the load than when lifting, for it would accelerate the descent at a rate that would be constantly increasing until the end of the run. By cutting out the series winding and allowing the motor to run on the shunt only, this is avoided. These conditions are brought about by means of the controller.

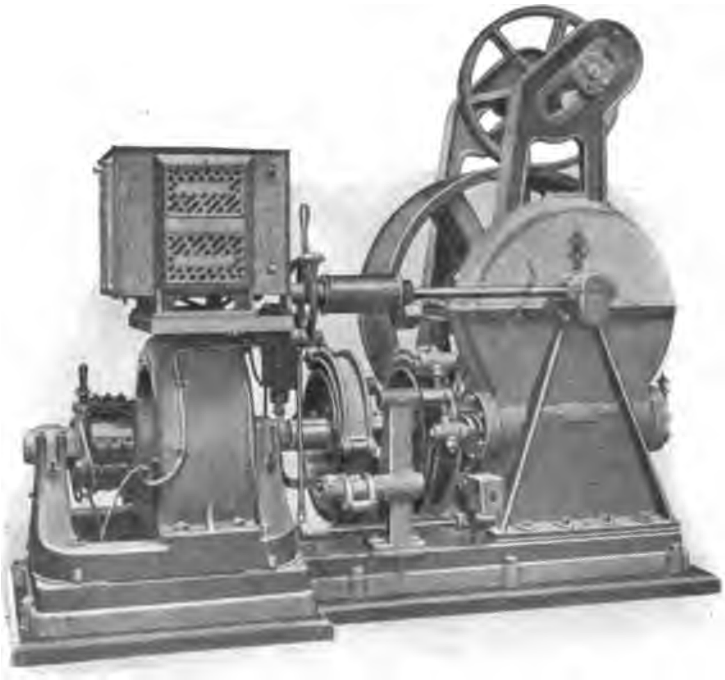


Fig. 12. Direct Connected Electric Winding Engine.

The offices of the controller are varied. It has first to turn the current into the motor through a certain amount of resistance; second, to gradually cut this out in steps as the motor increases in speed. At the same time it must gradually cut out the series winding in sections, and when the elevator is lowering, it also has to take care of the short circuiting of the armature, which will be explained later on. It consists usually of a switch for cutting out or breaking the circuit and for closing it, making suitable connections to the armature leads to cause the motor to run in the direction required. This switch is so arranged that when the circuit is closed, it releases an arm or a cross-head that drops by gravity and thereby cuts out the resistance in steps, doing it by moving the contact piece over a number of plates; the speed of its descent is governed by the escape of air from a dashpot. In some cases, instead of releasing the arm described above, it actuates a solenoid which lifts the arm or cross-head, its speed being governed in the same manner by the use of a dashpot. The breaking of the motor and solenoid circuit is done simultaneously just

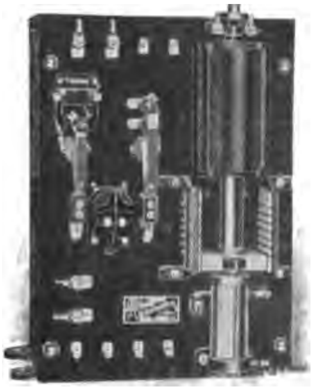


Fig. 13. Controller for Mechanial Operation.

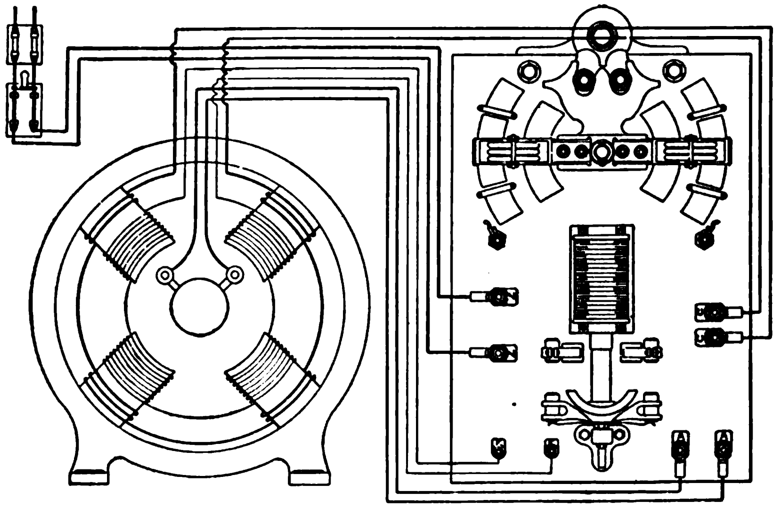


Fig. 14. (A) Wiring Diagram for Mechanical Controller.

prior to the stopping of the elevator, and where the speed of the elevator, or the weight of the loads it carries make it desirable, the controller is so constructed that when the line circuit is broken for stopping, while the elevator is lowering, it cuts in a certain amount of resistance with the armature, causing the E.M.-F. in the armature to pass through this resistance, thereby retarding the speed of the motor. This E. M. F. becomes weaker as the speed of the armature decreases, until it finally ceases with the motion of the motor. This method of bringing the elevator motor to a standstill is used in all standard makes of electric elevators to-day, and has been in use since about 1895. In addition to this, a mechanical brake, operated from the rock-shaft of the machine itself, and also a separate mechanical brake, operated electrically by a solenoid, are used. In the case of the latter, the solenoid is so arranged that it releases the brake when the circuit is closed.

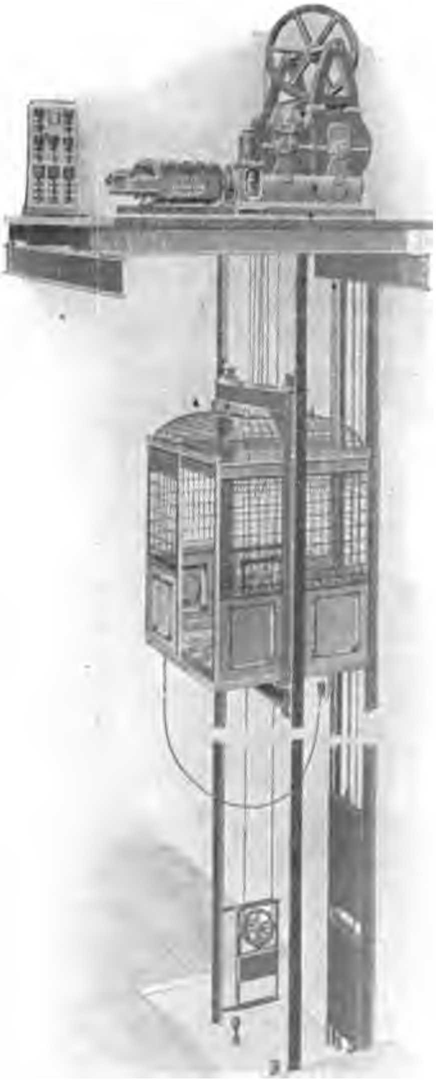


Fig. 15. Electric Elevator with Overhead Driving Mechanism.

This method of stopping and starting, just described, is the one generally used with a mechanical arrangement for operating the elevator; that is to say, with a hand cable or a lever-operating device; the cutting out of the resistance upon the starting of the elevator is purely mechanical. The arm or cross head on the controller, which cuts out the resistance in steps, is made to move over the contact pieces arranged for this purpose, either by gravity or by a solenoid which moves the arm or cross head; for these controllers are made both ways. Some have an arm working at one end upon a pivot, the other end carrying the carbons over the contact pieces; other types have a cross head which ascends or descends according as gravity or the solenoid comes into action. The cross head always has two sets of contacts.

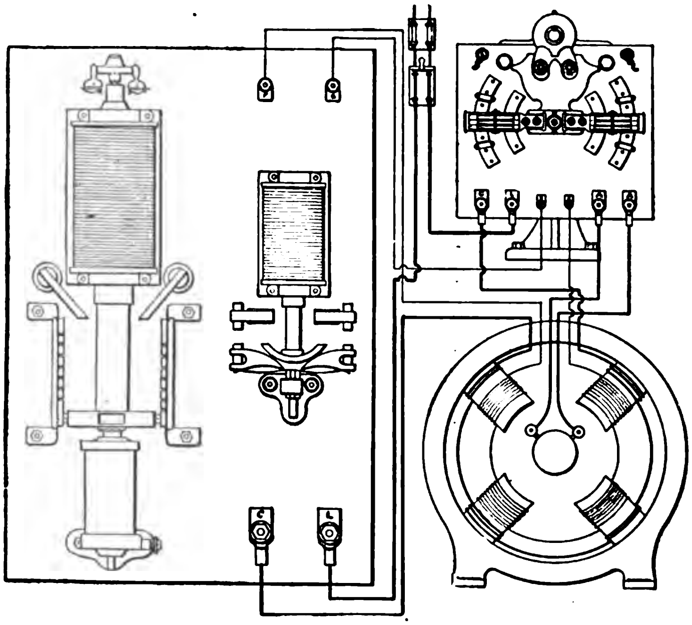


Fig. 16. (B) Wiring Diagram of Controller with Separate Switch.

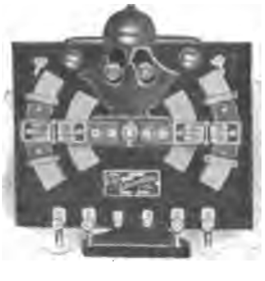


Fig. 17. Circuit Closing Switch.

The time of movement of the arm or cross-head, as the case may be, is governed by the use of a dashpot. The earlier forms of dashpots were filled with a light oil which would flow freely, and the movement of the plunger in the dashpot caused the oil to flow from one end of the cylinder to the other, through a very small opening, which was adjustable as to size. The time in which the arm or cross head passed over the contact plates was thus regulated, but it was found that the oil was affected by temperature, very cold weather making it sluggish and thick, and the action of the arm or cross head correspondingly slow. Sometimes where the oil was of a volatile nature, considerable waste would occur from this and other causes, and then upon closing the circuit the plunger would move very rapidly until it struck the oil and was brought up with quite a shock, and resistance was cut out quickly for two or three steps. This had a bad effect. Sometimes too, the attendant would neglect to replenish the dashpot at all and it would become entirely empty; then the resistance would be cut out so suddenly as to endanger the safety of the motor. To remedy this a dashpot of somewhat larger diameter was used, having a nicely fitting piston, and the air in the dashpot was imprisoned, being allowed to escape through a minute hole at the top or bottom, according to the way the dashpot was placed. The opening being adjustable by means of a screw, the arm or cross head could be made to pass over the contact pieces at any speed desired, the usual time allowed from closing the circuit to attaining full speed being from four to five seconds.

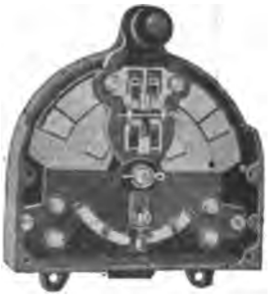


Fig. 18. Electric Operating Switch for Car.

With elevators running at a high rate of speed, however, say 300 feet per minute or more, this method of operation was not as perfect as could be desired; hence, there was devised what is called the electric control. This consists of a small switch located in the cab. From it wires are run in the form of the flexible cable to a point midway of the run of elevator, where the end of the cable is attached to the wall of the shaft, and from that point wires are run to the controller. This cable has to convey but a very small amount of current, simply sufficient to actuate one or more solenoids on the controller. These solenoids operate the switches which make and break the circuit in either direction. The throwing of this switch in the cab to the upright or central position, breaks the circuit always, and moving it either to the right hand or left will close the appropriate switch on the controller to run in the direction desired. This is done by actuating a solenoid on the controller, as before stated, which closes the switch to run the motor in the direction desired. The cable attached to this switch has to have at least three wires, one for the line, and the other two for their respective solenoids, but usually the cables are put in with a number of wires, so that if anything happens to any one of those in use, one of the dead wires can immediately be connected, and thus the necessity for replacing the entire cable is obviated.

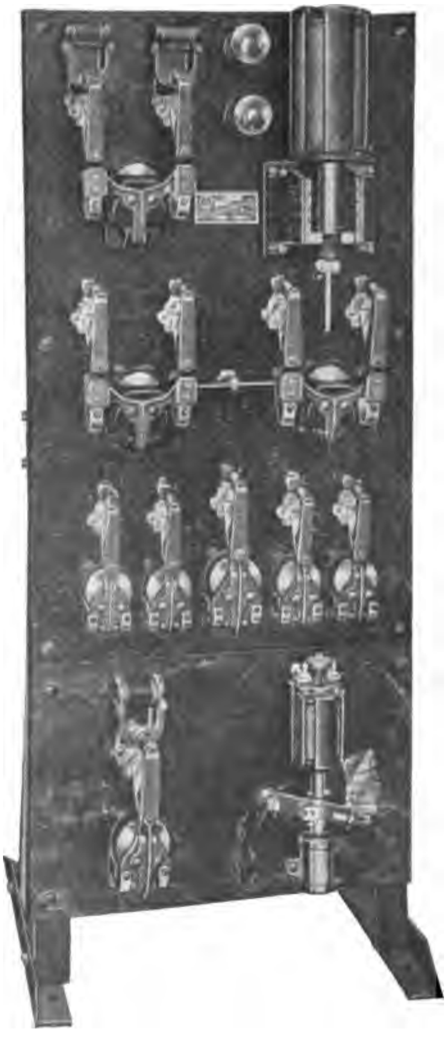


Fig. 19. Electrically Operated Controller.

Controllers of this description operate in various ways; in some, as soon as the line circuit is closed, a solenoid is actuated, which cuts out the resistance in the same manner as described as being used for the lever or hand-cable control. Another form of controller does it in a different manner, which will be described.

The armature is connected with a number of solenoids, each connected with a separate step of the resistance, and so arranged that they require varying amounts of current to actuate them, and the E.M.F. in the armature actuates these solenoids in rotation, the motor being started up at first and running slowly, the E.M.F. in the armature is weak and actuates only the first solenoid, which then cuts out the first step of the resistance. As the speed increases, the E.M.F. becomes stronger and successively cuts, out through the other solenoids, all the resistances as the motor attains full speed. When the circuit is open for stopping the elevator, these solenoids all drop back to their original position and are ready for the next start, and they are used to cut out the resistances in either direction of the motor.

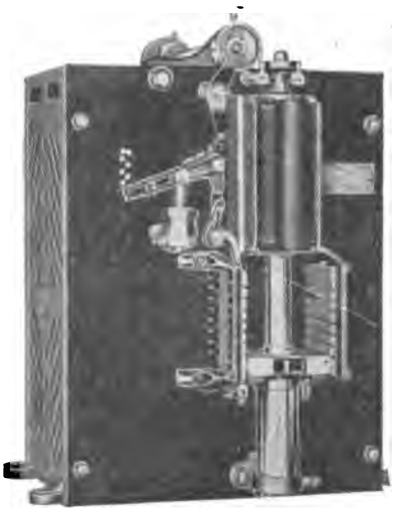


Fig. 20. Mechanical Controller, Variable Speed.

The E.M.F., as before stated, is frequently used as a means of retarding the motion of the elevator when a stop is desired, the most effective method being to introduce a set of resistances in the controller specially designed for the purpose. It is arranged on some elevators so that the E.M.F. actuates a solenoid which applies the brake, the latter being held off by a strong spiral spring. When the circuit is broken, the same movement that opens the switch, connects the armature with this solenoid, and if the elevator is running very fast, the E.M.F. being strong, applies the brake very hard. As the current in the armature, owing to the slowing down of the motor on the application of the brake, becomes weaker, the pressure on the brake becomes less, until finally it ceases entirely, and at this point the other mechanical brake operated by a solenoid, whose office is only to release it, is applied permanently by mechanical means. With this arrangement, one solenoid slows the motor and brings it to a stop, and having attained that point, the other solenoid releases its hold on the brake and allows the spring to apply it.

This latter arrangement, however, of using the E.M.F. to apply the brake, is simply a roundabout way of reaching the result—partly by mechanical and partly by electrical means—and is not really necessary; the short circuiting of the armature through resistances in the controller is all that can be desired.

In many elevators where a variable speed is desired, connection is made between the armature and a solenoid connected to a switch which is kept closed except when the solenoid is actuated. This switch closes a circuit between the shunt field coils and a bank of resistances in the controller, specially designed for the purpose, and has the effect of weakening the fields. This causes the motor to run at a greater than its normal speed, so that with a light load where the E.M.F. in the armature is not great, the elevator will always start up and run much faster than when a full load, or one nearly approaching it, is in the cage; for when the greater load has to be lifted, the E.M.F. in the armature becomes strong enough to actuate the solenoid, which opens the switch, thereby cutting out the resistance in the fields and leaving them stronger, and the speed of the motor immediately becomes slower. This is a very

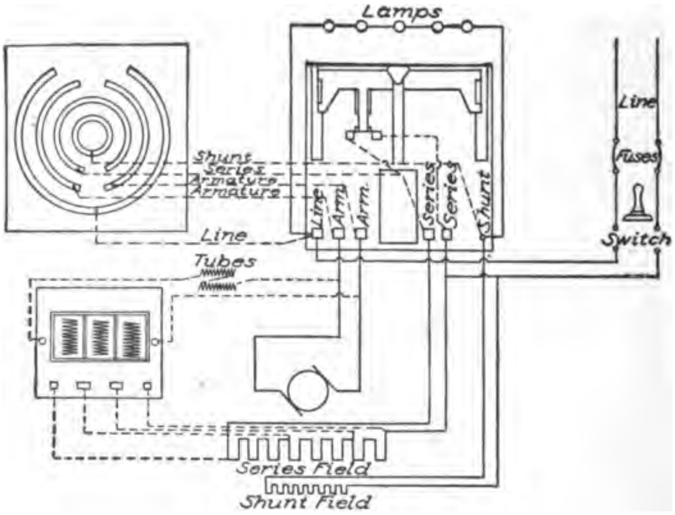
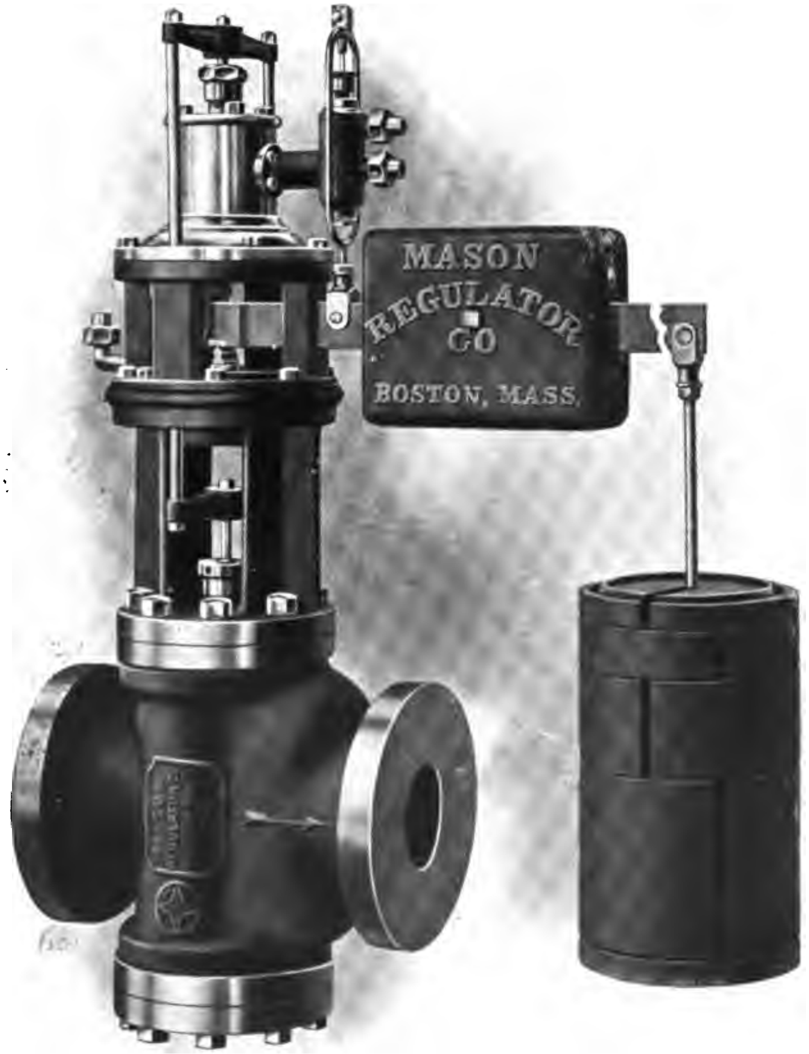


Fig. 21. (C) Wiring Diagram for Mechanical Controller.



MASON STEAM PUMP PRESSURE REGULATOR FOR HYDRAULIC ELEVATOR SERVICE

nice device and does its work automatically and is quite reliable.

The idea of weakening or strengthening the fields of a motor to gain or lessen speed is almost as old as the first electric elevators, but where current is taken from a public supply, or where only one elevator is used, it is usually not practicable to deviate from the methods above described. The ideal electric elevator, however, is one where a separate dynamo is used for supplying the fields and one for the armature. A field regulator connected with the dynamo supplying the fields can be placed in the cab, by means of which the operator can weaken or strengthen the fields of the dynamo supplying the current to the fields of the armature driving the motor. By this means a great variation in speed may be had. But while fairly economical in its operation, it is a plant that is expensive to install, and though it has been done in a few instances, there are not many of this type of elevator in existence.

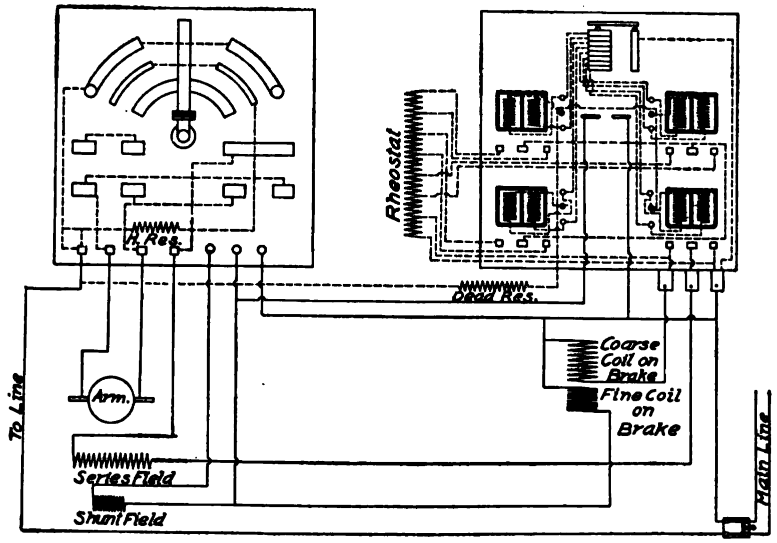


Fig. 22. (D) Wiring Diagram of Controller with Solenoid Cut-outs.

ELECTRIC LIMIT SWITCHES

It was found in operating electric elevators that more space was needed between the cab and the overhead sheaves at the upper part of the run, and that a deeper pit was also required at the bottom of the run on account of the occasional slip of the brake.

For frequently, although the mechanical, automatic or limit stop on the machine would break the circuit and apply the brake near the end of the trip, there were cases—for instance when the empty cage was required to ascend at full speed and the brake had become slightly worn and did not grip as firmly as usual—that the cage would go beyond the landing, and the additional space mentioned above was required to prevent a collision. This also happened sometimes at the lower end of the run when an extra heavy load was descending. A lack of care on the part of the operator in breaking the circuit in sufficient time, or the causes just mentioned, would cause the cage to run down to the bottom and bump. To avoid this, as an extra measure of safety, switches are sometimes placed at the extreme limit of the run, the line wire being carried up the hatchway through the switch and returned.

These switches are opened by the car automatically if it should pass a certain point, and the opening of this switch breaks the circuit and at the same time applies an extra strong emergency brake. The switches are operated by means of cams attached to the cage.

MISCELLANEOUS ELECTRIC ELEVATORS

There are one or two other types of elevators that have been more experimental than practical in their nature, which will be mentioned here. One of them, the Pratt-Sprague, consists of a long screw running horizontally in bearings at either end, which is driven directly by a motor placed at one end. The screw runs in a nut having a cross head, which travels on guides horizontally, the same as the cross head of a horizontal hydraulic, and is supplied with sheaves on either end. The construction of the machine is such that a double set of traveling sheaves and also fixed sheaves is necessary. The cables are rove over these sheaves similar to the method described for the horizontal hydraulic, and the motor, of course, is reversible.

One of the principal features of this type of machine was the construction of the nut which traveled on this large screw. It was supplied with steel balls on the pull side of the screw, and they ran close together in single file through a channel, which carried them around through the threads of the nut and caused them to return to the other end of the same after they had passed through. Of course, there had to be so many of them that they completely filled the channel from one end to the other, and it was thought that their use would reduce the friction to a minimum. It was found, however, in practice that they would get flat spots on them and cease revolving, and where they did this they would cut grooves or scores in the thread of the screw, which latter was a serious matter. They are very prone also to become deranged, and their operation was not as economical as had been anticipated.

Very few of these elevators are in use at the present time. The controlling device, however, was quite novel and the operation of the cage very agreeable and pleasant. The control of the motor driving this screw was effected by means of a small pilot motor operated in turn by means of push buttons in the cage.

Another type of elevator was that devised by Mr. Fraser, of California, the driving mechanism of which consisted of two motors set one above the other. They were necessarily slow speed motors, and each one had upon the armature shaft sheaves of about 20 inches diameter. The motors themselves ran at a speed of about 420 r.p.m., and the cables were so arranged as to form a double bight or loop below, in each of which one of these pulleys on the armature shaft ran as shown in the accompanying illustration. The upper ropes of the cables had sheaves carrying them and running in a frame, to one of which was attached the car cable, and to the other the counterpoise cables. These motors ran in opposite directions, and in the cab were placed rheostats for weakening or strengthening the fields. By this means the speeds

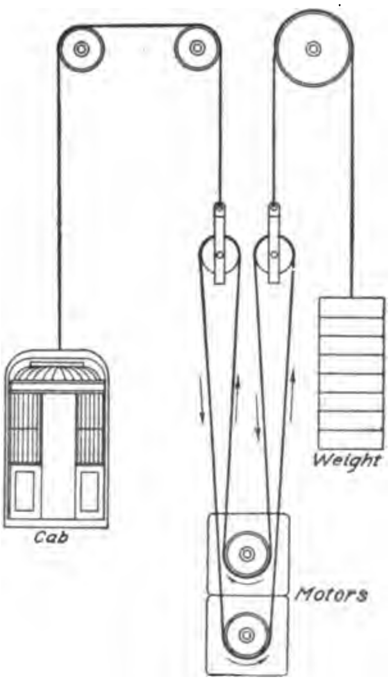


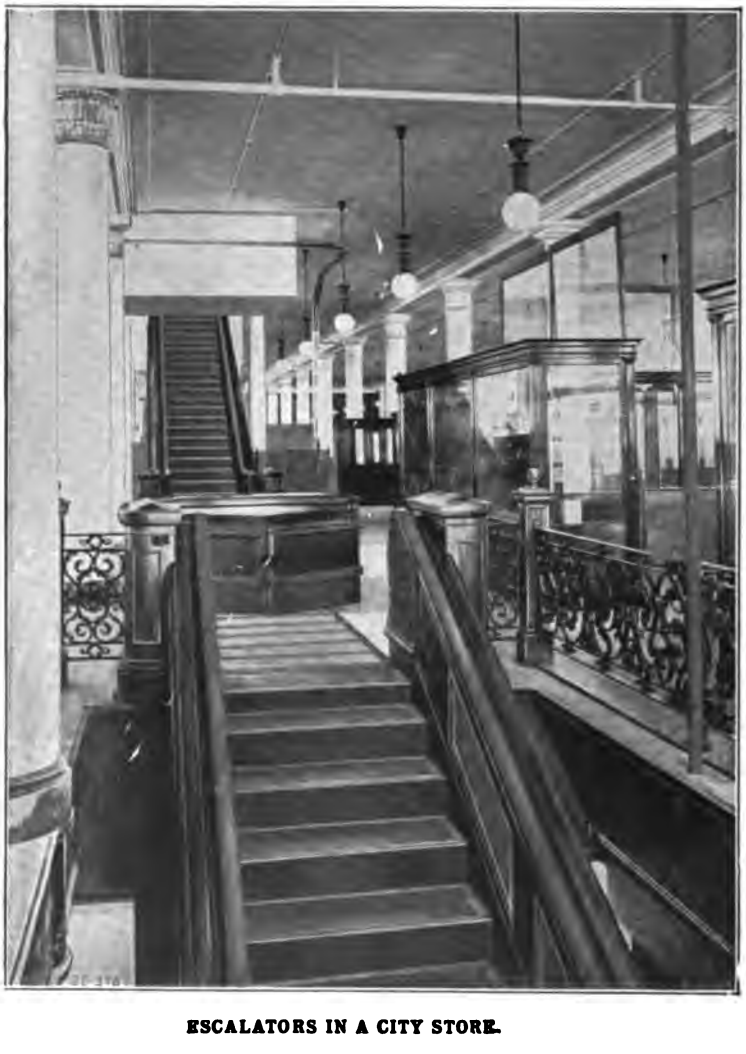
Fig. 23. Diagram of Fraser Elevator.

of the motors could be varied. By reference to the diagram illustrating this description, it can readily be seen that when both motors were running at the same speed, no motion of the car was obtained, but by varying the speed of either motor the car would run at a speed equal to half the difference of the two motors. No reversing apparatus was needed with these motors; they ran continuously in one direction, the motion of the car being gotten entirely by the change in speed, and the most desirable stops and starts were obtained. But the machine was very severe on the cables, so destructive in fact that they had to be renewed frequently; and taking it altogether, it was not found as desirable a machine as had been anticipated, either from the point of economy or maintenance, but results in operation were all that could be desired, including the speed attained and smoothness of stops and starts.

ELEVATOR ACCESSORIES

An elevator is really a vertical railway, but differs from one running on horizontal rails in that it does not use wheels, but slides on its track, and in order to avoid friction as much as possible, the cage should be hung centrally. The rails used for the cage to travel on are, in the more common types, usually of wood, hard maple being the material mostly adopted, and it is kept constantly lubricated with some form of grease. The guide ways after some weeks' use become rough and dry from various causes, principally from the rubbing off or evaporation of some of the component parts of the grease, and also from the accumulation of dust, which sticks readily to the lubricant. They then have to be cleaned off and relubricated, the object being of course to keep them as smooth and free from friction as possible.

Great care has to be taken when installing them to have them in perfect alignment and the joints very even; and maple, being a wood that is prone to warp, has to be put on in short pieces, the usual lengths being about four feet. The ends of these guides are tongued and grooved to fit into one another, and where the guide posts, to which they are attached, are made of wood, they are fastened thereto by means of appropriate lag screws, the ends of which are recessed into the face of the guides. The shoes on the cage



ESCALATORS IN A CITY STORE.

which run on these guides are usually machined to fit, and are made as smooth as possible at their faces of contact.

The device generally used for stopping the cage in case of a sudden descent, caused either by the breakage of the cables to which the car is suspended or by the derangement of any part of the machinery, is a pair of dogs, one placed in each guide-shoe beneath the car on opposite sides. These dogs are in the form of an eccentric, the outer face of which is supplied with coarse teeth, which, when the dog is revolved on its axis, come in contact with the guide strips; and as these teeth enter it, the descent of the car causes a further partial revolution of the dogs, so that the guides become tighter and tighter as the car descends, and bring it to a stop. This operation takes much less time to occur than it does to describe it here, the fact being that after the dogs begin to catch, the car descends but a very few inches before it is brought to a dead stop.

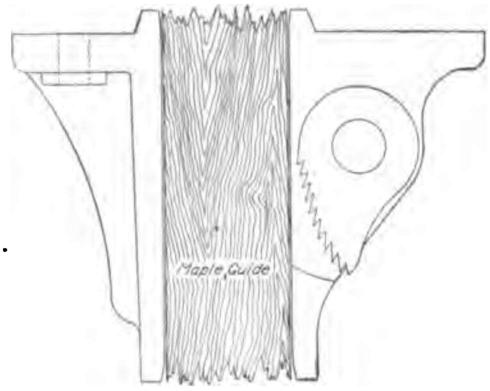


Fig. 24. Eccentric Safety Dog.

These dogs were originally used in connection with a spring for throwing them; hence when they acted at all they acted very quickly and before the platform had gained much headway, and while this was quite satisfactory in a slow running elevator, it was found to be quite objectionable with elevators of high speed—the sudden stopping producing a severe shock to the occupants of the cage—and moreover there were many cases where the elevator would descend rapidly, and the dogs failed to act, because they depended on the severing of the hoist cables for their action. They were operated by a spring which, being held in tension by the weight of the cage on the hoisting cable, would never act while that tension existed. Hence, if the cables were to break at or near the drum of the machine—the machine being located in the basement—these cables had to pass from the drum up and over sheaves at the top of the hatchway and it would require considerable power to drag them over these sheaves. This would be sufficient in itself to hold the spring out of action.

With the introduction of the safety governor, however, this trouble disappeared. The governor is a revolving sheave having within its rim dogs or arms set upon pivots and held in place by means of strong springs, either spiral or flat. These springs are so adjusted that the normal speed of the elevator does not affect either them or the dogs, but should the speed of the elevator exceed the normal by about 25 per cent, the centrifugal force exerted by these dogs, which are weighted somewhat, will overcome the tension of the springs, and they will fly out beyond the rim of the sheave, catching on a stand in which the sheave runs and stopping its revolutions entirely.

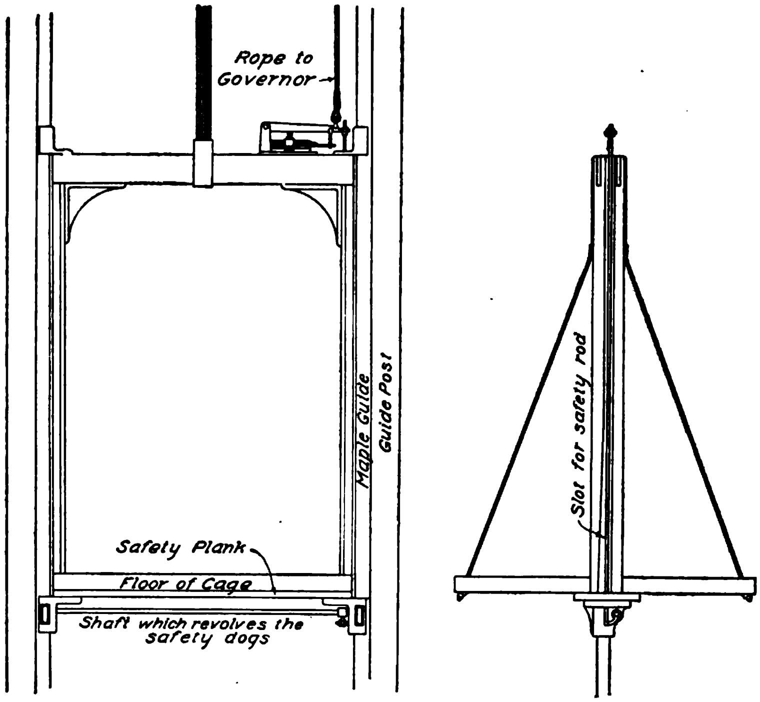


Fig. 25. Arrangement for Throwing Safety Dogs.

Now this sheave has a V-shaped groove in which runs a manila rope about $\frac{3}{4}$ inch in diameter. One end of this rope is made fast to a lever on the top of the cage, which operates the safety dogs, the other end is carried down the hatchway and around another sheave at the bottom and back again up to the cage, where it is attached at some convenient point, usually to an arm placed on the stile for that purpose. This sheave, which runs in the bight of the governor rope, is in a frame, which runs on guides and has a moderately heavy weight attached below it which serves the double purpose of keeping the governor rope taut and of taking up or compensating for the stretch of the rope. It also gives the necessary tension for driving the governor, and when the sheave in its revolutions throws out the dogs and stops itself, as before described, the V groove in the sheave grips the governor rope tightly and thereby pulls on the safety lever on the cage and throws in the safety dogs. It can be readily seen that with an appliance of this kind, the cage would have to descend quite a

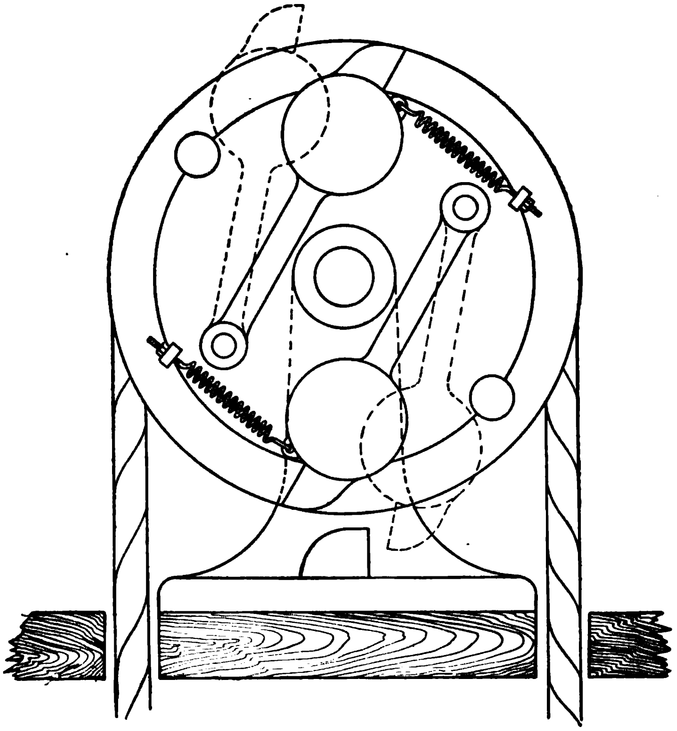


Fig. 26. Diagram of Safety Governor

distance before its speed would increase sufficiently beyond the normal to actuate the governor, and for this reason the style of safety dog described above, which was the first form introduced, was very objectionable, on account of its sudden stopping of the cage at the high speed it had attained by the time the dogs were thrown in. Therefore a modification of it was introduced in the form of a chisel, which, instead of catching into the guide strip as suddenly as the eccentric dog, would plane it out for quite a length, only entering deeper after the car had descended some little distance and thereby bringing the cage to a more gradual stop.

The form of safety governor described above is the one now in general use; the earliest form, however, differed slightly from it, being a governor having arms with balls on the ends, and revolving horizontally. The same method of driving it, however, was used, except that this governor was placed on the cross beam of the cage and threw the safety directly itself.

A still earlier form of this type of governor was used at the top of the hatchway, many years ago, but not driven by a rope. In the case here referred to, drums were used at the top of the hatchway, and separate cables from the hoisting engine were run directly to the drum overhead, terminating there. Other cables were run from that drum down to the cage, so that there was a constant winding of one set of cables on the drum and unwinding of the others, according to the direction the elevator was going. This drum had on its axis a gear wheel, which drove the governor, and the governor, in that case released a very heavy weight placed on the end of the lever. The dropping of the weight applied a powerful brake to the rim of the drum. This style of governor is not much used at the present time.

With the introduction of higher speeds in elevators a guide post and guide combined in one, and made entirely of steel, was devised and used, and it is in use to-day with all the high-class elevators; but its introduction, while giving greater smoothness of operation and offering many advantages that the wooden guide did not possess (that of remaining in alignment and consequently giving smoother action being the principal one), caused the necessity for a different form of safety than the eccentric or chisel dogs, before described, which were not applicable to this form of guide, hence a new device had to be introduced. This was in the form of a powerful pair of nippers placed below the car, one on each side. The inner ends of these nippers on being forced outward, caused the jaws of same to grip the steel guides with tremendous force, but the means of applying them being gradual they did not stop the cage suddenly but allowed it to slide several feet, bringing it gradually to a stand.

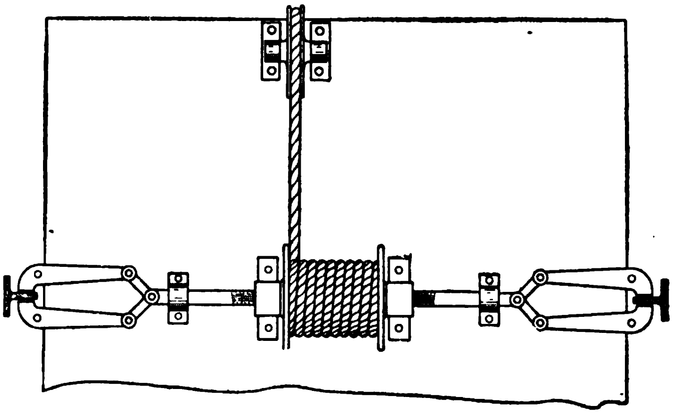


Fig. 27. Safeties for Steel Guides

The form of governor used to actuate these safeties is similar to that described above. The pulling of the governor rope causes the release of a very powerful coil spring under the car, which forces the dogs into action. There are several forms of this device, none of them differing materially, except in the method of applying the power to grip the guides, one or two of them dispensing with the coil spring, before mentioned, and using a powerful screw and knee joint. The screw is operated by the end of the governor rope, which is coiled several times around a spool or barrel on the body of the screw. The governor rope is gripped by the governor, and the descent of the car uncoils the governor rope off the spool, which is made to revolve, and, being attached to the screw, causes it to revolve. This action causes the knee joints to force the long end of the nippers apart, the short ends gripping the guides powerfully.

Another point in which the elevator differs from the horizontal railway is that in moving a load on an elevator the force of gravity has to be overcome as well as that of inertia. Hence, it is found to be economical to counterbalance the cage, and for that reason slides very similar to those on which the cage travels, but lighter in construction, have to be provided, in which a counterpoise weight travels. Sometimes more than one of these counterbalance weights are used, in some cases running in separate slides, in others, varying with the conditions, with each weight having a slide to itself.

When a counterbalance weight is used, which is attached directly to the cage, it can never be as heavy as the empty cage by several hundred pounds, depending largely upon the height of the building and the number of cables attached, for when the cage is at the top of the run, these cables hang over on the opposite side of the sheaves and have the effect of further counterbalancing the cage. The weight of the cage itself must therefore be greater than the combined weight of these cables and the counterbalance weight, otherwise, the cage would not descend when empty. When it becomes necessary to have the counterbalance weight fully as heavy as the empty cage, or, as occurs in many instances, it is required to be greater than the cage, this counterbalance weight has to be attached by means of cables running over sheaves at the top of hatchway to the opposite or back side of the hoisting drum. Where a cage is large and consequently quite heavy, the attaching of a counterpoise to the cage itself, as well as to the rear side of the hoisting drums, is done as a means of relieving the hoisting cables of a part of the weight they have to carry, and this adds to their durability and safety.

In the case of the electric elevator the over-counterbalancing of the cage is found to be quite economical in this way. An estimate is made of the average load which the elevator has to lift in its daily service, and it is over-counterbalanced to about this amount, the result being that, with the average load, the only power to be exerted in moving it will be that necessary on account of the friction of the machinery. For instance, it may be estimated that the average load of the elevator will be 500 or 600 pounds, although it is built to lift say 2,000 pounds. If it is overweighted this amount, it will be on a balance with the average load, and the amount of power required to move it will be a minimum.

This arrangement is found to give very good results as to economy in operation, but of course in order to get the very best results the cage should be built as light as possible commensurate with the requisite strength and stability; for if the cage is made unnecessarily heavy and it has to be counterbalanced equivalent to its weight, there is that much heavier body of material to start and stop each time the elevator is operated, and there is that much greater inertia to overcome, which consumes power. The necessity, therefore, of building everything as light as possible will be readily seen.

Where two counterbalance weights are used running in one slide, it should be an invariable rule to place the heavier weight, which is always that one attached to the rear side of hoisting drum, below the one attached directly to the cage, for there is a liability at times of counterbalance weight cables breaking, the same as there is with hoisting cables. Should this occur with the drum or heavier weight above the cage weight, the consequences would be disastrous, for combined they would weigh considerably more than the cage, and in falling would rush it upwards to the top of the hatchway at a great speed, provided of course that the cables by which the car weight was attached did not give way. Where the cables of the lower weight pass the upper weight, the latter is usually slotted throughout its whole length to allow their passage.

The best form of counterbalance weights used at the present time in elevators is made in sections so as to be readily changed or adjusted when desired. They consist of a head and bottom weight, which are usually provided with suitable guide shoes to run on the slides, and between them are shorter weights, which do not touch the guide, and which are called subweights. The whole number of weights are held together by means of strong iron rods with double nuts at either end. These pass through holes cast in the upper and lower sections of the weight, and the intermediate or subweights are held in position on these rods by means of grooves in their ends, which fit over the rods, the whole being clamped together firmly by means of the nuts just mentioned.

Sometimes, where the counterbalance weight is necessarily very long, a middle weight with guides on it is inserted, through which the rods holding in the subweights pass, thus giving it greater rigidity and safety.

A very important part of the elevator is the overhead sheaves and bearings. In the earlier forms of elevators, these bearings were set on wooden beams overhead, passing across the hatchway in the proper direction to let the cables drop where required. In later years, however, general practice seems to lean to the use of steel I-beams for this purpose, and they are certainly much safer in case of a fire occurring in the building. It frequently happens in case of a fire that the elevator is one of the principal means for getting people out of the building, and where these beams are of steel there is no doubt as to their greater safety under such conditions. The sheaves should always be as large as can possibly be used under the circumstances,—never less in diameter than the drum around which the cables wind—and the rule usually adopted is that the sheave should be at least 40 times the diameter of the cable which is to run over it, and as much larger than that as the conditions will permit. It is also very important that the score of these sheaves should fit the cable very well, otherwise, with heavy loads the latter becomes distorted, and even under the best conditions the wear of the cable will be rapid unless lubricated. For this purpose, there is nothing better than raw linseed oil applied with a brush, and it is very much improved in usefulness if a small quantity of the finer quality of plumbago be mixed with it. This material when unrefined is full of grit, and is put on the market in this condition for use as facing for moldings in foundries. It is very essential that this kind be not used, for the presence of the grit will have exactly the oppposite effect to that intended. After the plumbago has been carefully freed of all the grit it contains, it is a very good lubricant and in this condition it is very serviceable, both for the purpose just described and, in connection with grease, for the slides.

CABLES

Should the wires of the cables used in hoisting be run perfectly parallel to one another, they would not only last longer but they could be subjected with safety to a much greater strain, but that is found to be impracticable with running ropes, hence they have to be twisted, first in strands of 19 wires each, then six of these strands are twisted together around a center or heart made of hemp. The object of this arrangement is that in working over the sheaves the wires may rub on something softer than themselves and not abraid, for the parts of a hoisting cable when in use undergo many changes in position. For instance, when passing up the hatchway, the parts remain normal or as they were when made up, but when they come to the sheave the strands necessarily change positions slightly, being bent in a circle, and after passing over the sheave and down on the other side they change again to nearly the original position. As they are twisted around one another, different parts of the same cable change their relative positions quite frequently, for their very shape—being spirally wound around one another—causes them to roll slightly in the grooves of the sheave, and they do not always fall into exactly the same position when they return. Hence, the absolute necessity for some sort of lubrication. This change of position or twisting of the cables has made it advisable in cases where a large number of cables are used together (say for instance four or six cables running over one sheave) to use them alternately of right and left hand lay, the meaning of which is that some cables are twisted right-handed and others left-handed, and by using them alternately in this way they serve to correct the action of each other and prevent many minor troubles that will occur when laid up alike.

The scope of this article will not permit going into details relative to the proper fastening of the cables, which is a very important feature, but which is really in the hands of the elevator constructor, and with which the attendant has little to do.

The journals of the gudgeons or shafts upon which the sheaves revolve should always be of soft strong steel and of ample diameter, and the boxes in which they run should be lined with a very good quality of babbitt, and should be provided with good lubricating facilities. They are parts of the elevator that are neglected perhaps more than any other. Being at the highest point and out of the way, they are very seldom noticed, but at the same time too much emphasis cannot be placed upon the absolute necessity for properly attending to this important feature of the machine.

The operating cable, owing to the impossibility of following the rule laid down for the hoist cables regarding the diameters of sheaves, is usual to make of a much finer wire, and the number of wires to a strand is also greater. It is usually that kind of wire rope which is termed tiller rope, and is soft and flexible. The diameter is almost invariably ½ inch, except in cases where the lever device is used, when the necessity for a rope of that size does not exist. The ½-inch diameter is used principally because it is convenient for the hand, and it is seldom that a larger sheave than 12 inches is found practicable, but in any case, whether for hand cables or hoisting cables, iron ropes should always be used. It is true that a steel rope has a greater tensile strength, but the bending over the sheaves causes it to crystallize much more rapidly than an iron rope does, and it will consequently commence to crack sooner. The very best iron for this purpose is either Swedish or charcoal iron, which are very nearly pure, exceedingly ductile, and will stand the bending and straightening for a much greater length of time than a steel rope.

Wire cables have, in some instances, been known to run without fracture for eight, ten, and even twelve years, but there are very few in constant use that last more than three or four years. Some do not last longer than two years where subjected to constant and severe service, and in any case they should, on general principles, even if showing no outward signs of deterioration, be changed for new ones at the end of five years, under the most favorable circumstances. Cracking occurs very gradually and can readily be detected long before it actually occurs by the exterior appearance of the rope, but there are many cases where ropes crack inside before they do on the outside, and this can only be discovered by getting the rope entirely slack and slightly untwisting it so that an examination of the interior can be made. Holding one's hand gently on the rope while it is running will frequently detect a cracked wire if it be on the outside, but an examination of this kind must be carefully made to be of any service.

In regard to sheaves, sometimes an arm will crack through an undue shrinkage strain brought about possibly in some cases by disproportion in the design, or by unequal cooling in the foundry. In such cases the crack usually opens quite wide, but where it occurs from undue shock or jar, the fracture may occur and remain closed, so that it is not detected. Still the sheave is unsafe. Usually this can be perceived by care on the part of those in charge, for when the arm containing the fracture is in such a position that it is not subjected to the strain of the cable running over it, the crack, however minute, will open slightly, and it is liable to absorb or take in a minute portion of the oil which is generally on the sheave and which runs down from the journal boxes. This arm when it comes around to that point where it is subjected to compressive strain will force the oil out of the fracture in the form of a small line projecting above the surface of the sheave. It requires a sharp eye to detect this, but it can be seen with care, and many a possible accident has been avoided by the acuteness of the attendant in this respect. It is here mentioned for the benefit of those readers who may be in charge of elevators.

AIR CUSHIONS

About 1878 Mr. Gray, of Cincinnati, conceived the idea of an air cushion as an extra means of safety for elevators, and obtained the first patent for a device of this kind. The air cushion consists of an extension of the hatchway below the lower landing, and is in the form of a strongly enclosed air-tight chamber open only into the hatchway above. The guide posts are run down into this hatchway and the cage is made to fit it rather closely. This is usually done by fastening strips of thick rubber or leather below the floor of the cage, and allowing them to project to within about ½ inch of the sides of the air cushion. Now in case the cage should break loose from the cables, it will descend until, having entered this chamber a certain distance, the air contained within the chamber is compressed sufficiently to resist the further descent of the cage. At this point it begins to escape through the margin left all around the sides and the speed of the cage's descent is retarded until it sinks gradually to the bottom of the chamber without shock or jar.

The margin all around the cage for the escaping of air is a very essential feature to the success of this device. Many errors were made in some of the earlier forms of this device, owing to this feature not being well understood, for it is quite possible, where the air is confined too closely, to stop the cage violently; in fact, this will be the effect if the air is not allowed to escape. On the other hand, if too wide a margin is left, the effect desired will not result. Great care has to be exercised to have the chamber forming the air cushion air tight, strong enough to resist the strains that will be brought to bear upon it, deep enough to enable the car to come to a stop gradually, and to have the air space around the car just right to allow the air to escape in sufficient quantity to prevent a shock, and at the same time not fast enough to allow the car to drop too quickly after it enters.

The usual depth of the air cushion is about 8 or 9 feet and the space or margin left between the cage and sides of air cushion is from $\frac{3}{8}$ to $\frac{1}{2}$ inch. Some modifications are usually made after the work is finished by dropping the cage from a moderate height and noting results, before allowing it to drop the full extent of the run. This is an experiment that should not be performed by inexperienced persons, for accidents have frequently happened even to men thoroughly experienced in the business.

REVIEW QUESTIONS

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are samples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES

PART I

1. In what respect did the first locomotives differ from the modern locomotive?

2. Explain Whyte's system of classification.

3. What is a *compound locomotive?* Give its advantages.

4. What methods are in use for supporting the crown sheet?

5. What was the name of the first locomotive built in America? When was it constructed?

6. Give the names of some of the early locomotives built in America?

7. Describe the action of exhaust steam in creating draft in the front end.

8. Name the types of fire-boxes commonly used.

9. What created the demand for a wide fire-box?

10. Determine the principal dimensions of a tapered stack for a locomotive boiler 70 inches in diameter, the nozzle being 2 inches below the center of the smoke box.

11. Compute the thickness of the sheets of a straight-top locomotive boiler, 70 inches in diameter, carrying a boiler pressure of 200 pounds per square inch, the pitch of the stay bolts being 4 inches.

Ans. { Thickness of shell = .67 inches.
" " fire-box side and fire door sheets = .36 inches.

12. What parts comprise the *front end* of a locomotive?

13. Did American engineers give aid to the development of the locomotive in its early conception? If so, how?

14. What classes of locomotives are used for freight service?

15. In what portion of the throat and side sheets does the greatest amount of stay-bolt breakage occur?

16. How may the poor steaming qualities of a locomotive be improved?

17. What is a *tell-tale hole* and why is it used?

18. For what purpose is a *brick arch* used in the fire-box of a locomotive?

19. For what purpose is a *superheater* used?

20. What was one of the chief errors made in the design of the earlier locomotives?

21. What resistance is offered to shear by one rivet $\frac{7}{8}$ inch in diameter? Ans. 33,071 lbs. per sq. in.

22. What per cent of the coal is lost as sparks from a locomotive?

23. Name five different types of compound locomotives.

24. What means are employed in staying the flat surfaces of locomotive boilers?

25. Explain the passage of steam through the cylinders of a cross-compound locomotive.

26. What two types of stacks are used, and which is to be preferred?

27. What are the arguments for and against high steam pressures?

28. What will be the stress per square inch on one-inch stay bolts used in a boiler working under a pressure of 200 lbs. per sq. in., the stay bolts being placed four inches from center to center?

Ans. 4,074 pounds per square inch.

29. State the factors entering into the development of the different types of passenger locomotives.

30. What is the object of making tube sheets thicker than the side sheets of a fire-box?

31. State the differences between a De Glehn and a Cole compound locomotive.

32. What is *draft* as used with reference to a locomotive front end?

REVIEW QUESTIONS

ON THE SUBJECT OF

LOCOMOTIVE BOILERS AND ENGINES

PART II

---

1. What effect does the changing of a valve from inside lap to inside clearance have on the events of the stroke?

2. What pressure in tons would be required to force a cast steel driving wheel center on an 8-in. axle? What allowance is commonly made for tire shrinkage?

3. State briefly how the dead center points are located.

4. What two types of valve gears are generally used in this country?

5. State the advantages and disadvantages of each.

6. What is the resistance, due to grade only, of a freight train weighing 2,000,000 pounds, moving up a grade of .9 of one per cent? Ans. 18,000 pounds.

7. What is the resistance, due to acceleration only, of a train weighing 200 tons that is accelerated from a speed of 50 to one of 60 miles an hour in a distance of one mile? Ans. 264 pounds.

8. State the two different forms of locomotive frames in use and give the principal features of each.

9. What is the tractive power of a simple locomotive having cylinders 18 inches in diameter, a piston stroke of 24 inches, driving wheels 62 inches in diameter, and working under a boiler pressure of 200 lbs. per sq. in.? Ans. 21,321.

10. What is meant by the terms *lead, outside lap,* and *inside clearance?*

11. What is the resistance, due to curvature only, of a passenger train consisting of a locomotive weighing 120,000 pounds and cars weighing 200,000 pounds, moving around a 4-degree curve? Ans. 616 pounds.

12. Describe the form and state the characteristic features of a locomotive throttle valve.

13. How should the reverse lever and throttle valve be manipulated as the speed of the locomotive increases?

14. What will be the resistance on a straight track, of a train of cars weighing 240,000 pounds running at a speed of 50 miles per hour?

15. A consolidation locomotive weighing 137,950 pounds has 117,400 pounds on the driving wheels. The weight of the reciprocating parts on one side of the engine is 680 pounds. The stroke of the piston is 26 inches. The diameter of the driving wheel is 56 inches.

(a) What weight of reciprocating parts must be balanced?

(b) What weight must be added to each driving wheel if the center of gravity of the counterbalance thus added is to be 19 inches from the center of the wheel?

Ans. { (*a*) 335 pounds.
(*b*) 57 pounds.

16. What changes are necessary if it is desired to increase the lead?

17. What different methods are employed?

18. Given a freight locomotive of a mogul type, having the following dimensions:

Weight on driving wheels, 127,500 pounds.
Weight on truck wheels, 23,000 pounds
Diameter of cylinders, 20 inches.
Stroke of piston, 26 inches.
Diameter of driving wheels, 64 inches.
Boiler pressure, 200 pounds.
Diameter of main driving axle, 9 inches.
Length of piston rod, 48 inches.
Horizontal distance from center line of frame to center line of rail, 7½ inches.
Distance from center of main rod to center line of frame, 20 inches.
Speed, 40 miles per hour.
Minimum radius of curvature of track. 955 feet.

Weight of main axle and drivers, 6,500 pounds.
Distance from center of main rod to face of wheel, 8 inches.
Distance from center of side rod to face of wheel, 2½ inches.
Diameter of cylinder stud bolt circle, 24 inches.

Determine

(a) The tractive force. Ans. 27,620 pounds.
(b) Maximum fiber stress in main axle. Ans. 9,036 lbs. per sq. in.
(c) Diameter of the crank pin. Ans. 6¾ inches.
(d) Diameter of the piston rod. Ans. 3.41 inches.
(e) Thickness of cylinder wall. Ans. 1.33 inches.
(f) Thickness of cylinder head. Ans. 1.49 inches.

19. When a distance signal is set in the danger position, what does it signify?

20. Determine the diameter of cylinders for a Pacific type passenger locomotive having 150,500 pounds on the drivers, a stroke of 28 inches, drivers 74 inches in diameter, and working under a steam pressure of 200 pounds. Ans. 24 inches diameter.

21. Give the name of the important parts which compose the running gear of a locomotive.

22. Define what is meant by a *main rod* and a *side rod*, and state why their section is made in the form of an I.

23. What factors must be considered in determining the rating of a locomotive?

24. Before undertaking the setting of the valves of a locomotive what preliminaries are necessary?

25. What do the signal colors—*red*, *blue*, *green*, and *white*—indicate?

26. What inspections should be made of the locomotive at the end of the run?

27. What is the difference between the *home signal* and the *advance signal?*

28. Why is a counterbalance necessary on a locomotive driving wheel?

29. Describe the two forms of cylinder and saddle castings.

30. What should be the length of the radius bar of a mogul locomotive having all drivers flanged, a rigid wheel base 15 feet 2

inches long, and a distance of 8 ft. from the front driver to the truck center? Ans. 5 ft. 11.2 in.

31. Explain the action of a safety valve.

32. State the advantages of using a leading truck on a locomotive. When are trailing trucks used?

33. What is meant by *permissive block signaling?*

34. Where should the reverse lever be placed when running with the throttle closed? Why?

35. What is the use of a relief valve on the steam chest?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE AIR-BRAKE

---

1. What form of air-brake was first used? State the principle of its operation.

2. What advantages has the New York air-pump over the Westinghouse nine and one-half inch pump?

3. Why are the feed-valve, equalizing reservoir, and pump-governor necessary?

4. If the brake-pipe is opened to the atmosphere either by the train parting, hose bursting, or the conductor's valve, why should the engineer's brake-valve be placed in lap position?

5. In double-heading, which engineer should have control of the air-brakes? Why?

6. What reduction in brake-pipe pressure is necessary to cause a light service application?

7. Sketch and explain the action of the Westinghouse automatic pump-governor.

8. What should be the capacity of the main reservoir for passenger and freight engines?

9. Give the five positions of the ordinary Westinghouse engineer's brake-valve, and tell what occurs in each position.

10. What is the purpose of the slide-valve feed-valve, and when does it act?

11. Explain the action of the Westinghouse quick-action triple valve in release, service, and emergency application.

12. What are the allowable brake-shoe pressures for freight cars, passenger cars, and locomotives?

13. Of what known fact does the high-speed brake take advantage?

14. In the high-speed brake equipment, what is the function of the automatic reducing valve?

15. Name three advantages of the Westinghouse "E T" equipment, and give a list of the principal parts.

16. If, after an emergency application is made with the "E T" equipment, the locomotive wheel should skid, what should be done?

17. Name the principal parts of the train air-signal system, and state how it is operated.

18. When the trainmen signal the engineer, why is it necessary to allow an appreciable length of time to elapse between successive discharges?

19. Why is the straight air-brake equipment used on electric cars for city and interurban service?

20. Why is this system not found on electric trains of more than two cars in length?

21. Name the different types of compressors used on electric cars, and state the advantages and disadvantages of each.

22. By using Fig. 88, determine the distance required in which to stop an electric car if the power is thrown off when running at a speed of 20 miles per hour.

23. What is the purpose of the conductor's brake-valve?

24. What is the leakage groove in the brake-cylinder and its purpose?

25. What is the difference between the straight-air and the automatic brake?

26. Why should the main reservoir be drained before each run?

27. How is the pressure regulated in the main reservoir?

28. How is a service application of the automatic brake made?

29. What provision is made to keep the pump always running slowly?

30. What is the use of the main reservoir?

31. What is it that tells the engineer when the brake-valve remains in release position too long?

32. What are the advantages of the "K" triple over the ordinary quick-action triple valve?

33. Why is it a waste of air to make a reduction of more than 20 or 25 pounds?

34. With the ordinary air-brake equipment, why is it advisable

to bring a long freight train to a full stop, in case a slow-down is desired?

35. In stopping a passenger train, why is it desirable to release the brakes just before coming to a full stop?

36. Describe the principal parts of the Westinghouse and New York quick-action triple valves.

37. In what way does the action of the Westinghouse and New York triple valves differ in emergency applications, and with what result?

38. What is the purpose of the pressure-retaining valve, and when is it used?

39. In what way do the Westinghouse and New York quick-action triple valves differ respectively from the plain automatic triple valves?

40. What changes are necessary in the ordinary air-brake equipment when transforming in into the high-speed brake equipment?

41. State the principle upon which the "E T" locomotive brake equipment operates, and how is it manipulated?

42. What special features does the Westinghouse "K" triple valve possess?

43. Can the ordinary quick-action triple valve be transformed into a "K" triple valve? If so, how?

44. State briefly the principle upon which the "K" triple valve operates.

45 Why do cars equipped with the "K" triple valve, mixed in a train, improve the action of the air-brake equipment?

46. Name the parts which constitute the foundation brake-gear.

47. Describe the automatic slack-adjuster.

48. What is the difference between the New York and the Westinghouse engineer's brake-valve?

49. How should the train be stopped in backing up a freight train? a passenger train?

50. How should the air end of the air-pump be oiled?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELEVATORS.

---

1. How does the plunger elevator operate?
2. How is the speed of a water-balance elevator controlled?
3. What is an electric limit switch?
4. What arrangement of packing is used for the pistons of hydraulic elevators?
5. How are air cushions arranged?
6. Describe the distributing valve used on the early steam elevators.
7. What kind of safeties are used with steel guides?
8. Describe the best form of limit valve for hydraulic elevators.
9. Describe the two earliest types of steam winding engines.
10. What is the function of a pilot valve?
11. What precaution should be taken with elevator cables?
12. What kind of cylinder lubrication is best for hydraulic cylinders?
13. Name three kinds of hydraulic elevators.
14. What safety device was used in connection with the spur-gear winding engine?
15. How is the Fraser elevator operated?
16. Explain the method of counter-weighting the cage and cables.
17. How is a pressure tank used?
18. Describe the method of mechanical control for electric elevators.
19. When two counterbalance weights are used, how should they be arranged?

INDEX

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

Page

A

- Air-brake 165–275
- Air-brake as applied to electric cars 254
  - air-compressor 259
  - automatic friction-brake 272
  - brake-cylinder 265
  - operating valve 266
  - pump-governor 261
  - reservoir 265
  - stopping a car 274
  - straight air-brake 255
  - train air-signal 273
- Air-brake equipment, use and care of 250
  - air-pump 253
  - angle-cocks 252
  - backing up trains 252
  - cutting out brakes 252
  - conductor's brake-valve 252
  - double-heading 252
  - emergency applications 251
  - engineer's brake-valve 253
  - pressure-retaining valve 251
  - running test 250
  - service applications 250
  - train inspection 250
  - triple valve and brake cylinder 253
  - use of sand 251
- Air-brake system
  - New York 229
  - Westinghouse 171
- Air-compressor 259
- Air cushions 373
- Air-pump, New York 229
- Air-pump governor 180
- Air-signal system, train 247
- Alternating-current systems 305
- American locomotive 19
  - longitudinal section of 42
- Ash pans 58
- Auto transformer 284
- Automatic air-brake 168
- Automatic brake-valve 212
  - charging position 213
  - emergency position 216
  - holding position 216
  - lap position 216
  - release position 216
  - running position 213
  - service position 216
- Automatic friction-brake 272
- Automatic slack-adjuster 242
- Axles 102, 117

B

- Baldwin superheater 77
- Bell cord signals 143
- Belpaire boiler 45
- "Best Friend of Charleston" locomotive 13
- Block system of signaling 150
- Blower 138
- Boiler performance, effect of different pressures on 68
- Brake
  - early forms of 165
  - emergency application of 175
  - release application of 175
  - service application of 175
- Brake gear 237
  - automatic slack-adjuster 242
  - locomotive driver brakes 244
  - locomotive truck brake 246
- Brake system 169

Note.—For page numbers see foot of pages.

Page

- Brake valve 181, 232
- Brick arches 60
- Brush arc system 298

C

- Cables 370
- Camel-back locomotive 14
- Catenary 284
- Central station engineering 297–323
  - alternating-current system 305
  - brush-arc system 298
  - Edison constant-potential system 298
- Circuit closing switch 354
- Cole compound locomotive 39
- Cole four-cylinder compound locomotive 30
- Combustion, rate of 66
- Commercial single-phase motor 281
- Commutator type single-phase motor 281
- Compound locomotive 30
- Connecting rods 111
- Controller 351
  - electrically operated 356
  - mechanical 352
- Counterbalance 100
- Counterbalance weight 368
- Crank-pins 103, 121
- Crossheads and guides 109
- Cylinder and saddle for locomotive 107
- Cylinders 125

D

- Daniel Nason locomotive 16
- Dead-center points, diagram for locating 89
- De Glehn compound locomotive 39
- Diaphragm 61
- Distributing valve 202
  - charging position 205
  - emergency lap position 209
  - emergency position 209
  - independent application of 210
  - independent release of 211
  - release position 206
  - safety-valve 211
  - service lap position 208
  - service position 207
- Double front rail locomotive frame 104
- Draft 61

Page

- Draft pipes 61
- Driving wheels 97
- Dwarf signals 152

E

- "E T" locomotive brake equipment 197
- Early steam elevators 325
- Eccentrics 88
- Edison Companies 301
- Edison constant-potential system 298
- Edison tube 299
- Electric elevators 349
- Electric limit switches 359
- Electric railways, single-phase 277–295
- Electrically operated controller 356
- Elevator accessories
  - bearings 370
  - counterbalance weight 368
  - guide ways 362
  - safety dog 363
  - safety governor 364
- Elevators 325–374
  - early steam 325
  - electric 349
  - hydraulic 334, 339
  - limit valves 347
  - lubrication 344
  - packing 344
  - water balance 333
- Emergency application of brakes 175
- Engine design 117
  - axles 117
  - crank pins 121
  - cylinders 125
  - frames 124
  - piston rods 123
- Engineer's brake valve, New York 232
  - emergency position 234
  - lap position 234
  - release position 234
  - running position 232
  - service position 233
- Engineer's brake-valve, Westinghouse 181
  - emergency position 185
  - lap position 184
  - release position 185
  - running position 182

Note.—For page numbers see foot of pages.

Page

- Engineer's brake valve, Westinghouse
  - service position 183
- Exhaust nozzles 63

F

- Fiber stresses, table of 120
- Fire-box 45
  - Belpaire 45
  - narrow 48
  - Vanderbilt 46
  - wide 48
  - Wooten 46
- Firing 153
- Fixed signals 148
- Flues 50
- Foundation brake-gear 237
- Frames of locomotive 124
- Fraser elevator 361
- Front end of boiler 60

G

- Governor, air-pump 180
- Grades 156
- Grates 57

H

- Handling trains 156
- Hayes 10-wheeler locomotive 15
- Heating surface 70
- High-speed brake 195
- High steam pressures 68
- High-voltage polyphase systems 315
- Horizontal hydraulic elevators 334
- Hydraulic elevators
  - horizontal 334
  - vertical 339

I

- Independent brake-valve 217
  - lap position 218
  - release position 218
  - running position 217
  - service position 217
- Injector 134
- Inside clearance 86
- Interchangeable brake system 169

Page

K

- "K" triple valve, Westinghouse 220

L

- Lap position of brake-valve 175
- Lead 85
- Lifting injector 134
- Lifting shaft 88
- Limit valves 347
- Link 88
- Link hanger 88
- Locomotive appliances 132
  - blower 138
  - dry pipe 139
  - injector 134
  - lubricator 141
  - safety valves 132
  - steam gauges 138
  - throttle valve 138
  - water gauges 138
  - whistle 138
- Locomotive boiler design 79
- Locomotive boilers 45
  - classification of, as to fire-box used 45
  - classification of, as to form 45
  - definition of 45
- Locomotive boilers and engines 11–163
- Locomotive driver brakes 244
- Locomotive engine 85
  - crossheads and guides 109
  - cylinder and saddle 107
  - frames 104
  - inside clearance 86
  - lead 85
  - main rods 111
  - outside lap 85
  - piston and rods 108
  - running gear 97
  - side rods 111
  - tender 116
  - trucks 112
  - valve 86
  - valve motion 86
  - valves 94
- Locomotive frames 104

Note.—For page numbers see foot of pages.

Page

- Locomotive operation 153
  - cleaning 158
  - emergencies 158
    - broken connecting rod 158
    - broken driving springs 159
    - broken side rods 158
    - broken steam chest 160
    - foaming 159
    - low water 159
  - inspection 157
  - repairs 158
  - running 153
    - feeding the boiler 154
    - firing 153
    - learning the road 156
    - use of steam 155
- Locomotive rating 129
- Locomotive truck brake 246
- Locomotive trucks 112
- Locomotives
  - classification of 20
  - historical development of 11
- Lubricator 141

M

- Magnetic speed indicator 291
- Mallet articulated compound 36
- Mallet compound locomotive 19
- Mechanical controller 352
- Movable signals 143

N

- Narrow fire-box 48
- Netting 60
- New York air-brake system 229
  - air-pump 229
  - engineer's brake valve 232
  - quick-action triple valve 235

O

- Outside lap 85

P

- Pielock superheater 73
- Piston rods 108, 123
- Piston valve 96
- Plain slide valve 94

Page

- Plain triple valve 191
- Plunger elevator 342
- Pony truck 112
- Pratt-Sprague elevator 360
- Pressure-retaining valve 194
- Pump-governor 219, 261

Q

- Quick-action triple valve
  - New York 235
  - Westinghouse 189

R

- Radial trailing truck 115
- Railway signaling 142
  - bell cord signals 143
  - block system 150
  - fixed signals 148
  - movable signals 143
  - train signals 144
  - whistle signals 142
- Rate of combustion 66
- Rating of locomotive 129
- Reach rod 88
- Reducing valve 219
- Release application of brakes 175
- Release position of brake-valve 175
- Reuben Wells locomotive 17
- Reversing lever 87
- Rocker arm 88
- "Rocket" 12
- Running gear of locomotive 97
  - axles 102
  - counterbalance 102
  - crank-pins 103
  - driving wheels 97
- Running a locomotive 153
- Running travel 194

S

- Safety dog 363
- Safety governor 364
- Safety valves 132
- Saturated steam 73
- Schenectady superheater 74
- Schmidt superheater 74
- Sellers injector 134

Note.—For page numbers see foot of pages.

Page

Semaphore 148
Service application of brakes 175
Shrinkage allowance, table 98
Side rods 111
Single front rail locomotive frame 104
Single-phase electric railway 277–295
Single-phase motor 283
Slide valve 94
Slide-valve feed-valve 186
Smoke-box 60
Smoke-box temperature, effect of different pressures upon 69
Spark losses 68
Speed indicator, magnetic 291
Spoke data 98
Stack 65
Standing travel 194
Stay-bolt breakage 55
Stay-bolts 52
Steam or branch pipes 60
Steam elevators, early 325
Steam gauges 138
Stephenson valve gear 87
  eccentrics 88
  lifting shaft 88
  link 88
  link hanger 88
  reach rod 88
  reversing lever 87
  rocker arm 88
  setting the valves 88
Storage battery, function of 312
Straight air-brake 168
Straight stacks 65
Straight top boiler 45
Superheaters 71
  Baldwin 77
  Pielock 73
  Schenectady 74
  Schmidt 74

T

Tables
  crank pins, working stress for 123
  dry pipe sizes 139
  fiber stresses 120
  forged steel billets 103

Page

Tables
  heating surface, ratio of, to grate area 71
  hydraulic pressures used in mounting axles 103
  hydraulic pressures used in mounting crank-pins 104
  locomotives
    classification of 21
    comparison of 19
  shrinkage allowance 98
  spoke data 98
Tapered stacks 65
Tender of locomotive 116
Three-wire, direct-current system 300
Throttle valve 138
Time tables 162
Tornado locomotive 19
Tractive force of locomotive 127
Trailing truck 115
Train air-signal 273
Train air-signal system 247
Train resistance 128
Train rules 160
Train signals 144
Trevithick's locomotive 11
Triple valve 169
  New York 235
    charging position 235
    emergency position 237
    lap position 236
    service position 236
  Westinghouse 189
    charging position 189
    emergency position 191
    lap position 190
    service position 190
Trolley voltage 277
Trucks, locomotive 112

V

Vacuum brake 169
Valve gears 87
  Stephenson 87
  Walschaert 91
Valve motion 86
Valves 94
  piston 96

Note.—For page numbers see foot of pages.

Page

- Valves
  - slide 94
- Vanderbilt fire-box 46
- Vauclain compound locomotive 39
- Vertical hydraulic elevators 339
- Von Borries compound locomotive 39

W

- Wagon top boiler 45
- Walschaert valve gear 91
- Water balance elevator 333
- Water gauges 138
- Water powers, development of 309
- Westinghouse air-brake system 171
  - air-pump governor 180
  - brake-valve 181
  - combined freight-car cylinder, reservoir, and triple valve 193
  - high-speed brake 195
  - main reservoir 179
  - operation of 175
  - plain triple valve 191
  - pressure-retaining valve 194
  - pumps 175, 177
  - quick-action triple valve 189
  - slide-valve feed-valve 186
- Westinghouse 9½-in. air-pump 175
- Westinghouse automatic friction-brake 272
- Westinghouse 8½-in. cross-compound pump 177
- Westinghouse "E T" locomotive brake equipment 197

Page

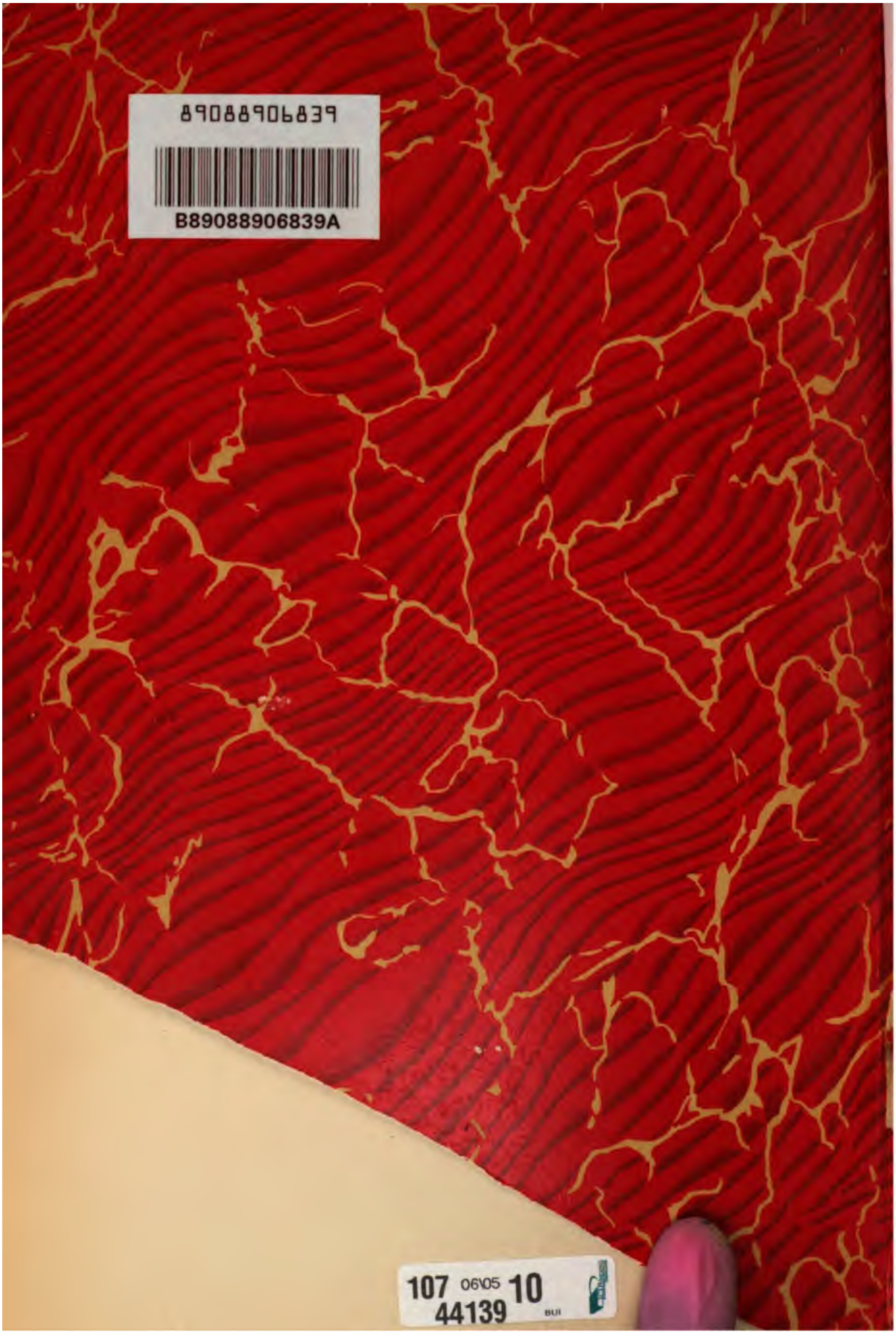
- Westinghouse "E T" locomotive brake equipment
  - automatic brake-valve 212
  - distributing valve 202
  - independent brake-valve 217
  - manipulation 200
  - pump-governor 219
  - reducing valve 219
- Westinghouse engineer's brake-valve 181
- Westinghouse "K" triple valve 220
  - emergency position 229
  - full-release position 224
  - full-service position 226
  - lap position 227
  - quick service 223
  - quick-service position 225
  - retarded-release 223
  - retarded-release position 227
  - uniform recharge 223
- Westinghouse straight air-brake 255
- Westinghouse train air-signal system 247
  - car discharge valve 249
  - reducing valve 247
  - signal valve 248
- Whistle 138
- Whistle signals 142
- Wide fire-box 48
- Wire cables 372
- Wooten fire-box 46

Z

- Zone of fracture 53

Note.—For page numbers see foot of pages.

107 06\05 10
44139 BUI



89088906839

B89088906839A

107 06\05 10
44139
BUI

89088959945

b89088959945a

K.F. WENDT LIBRARY
UW COLLEGE OF ENGR.
215 N. RANDALL AVENUE
MADISON, WI 53706